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Foreword

We cordially welcome you to the 14th International Conference on Construction Applications of Virtual Reality (CONVR 2014). This year we are organising the conference at University of Sharjah in Sharjah, UAE. UAE is one of the progressive and exciting countries in the world with billions of dollars invested each year in construction and infrastructure projects. UAE houses Burj Khalifa, the world's tallest building at 2,716 feet (828 meters) and 160 stories. The University of Sharjah known for its beautiful Islamic architecture campus is a pioneer in academia, scientific research and arts in UAE and the GCC region.

CONVR is one of the world-leading conferences in the areas of virtual reality, augmented reality and building information modelling applied to construction processes. Each year, more than 100 participants from all around the globe meet to discuss and exchange the latest developments and applications of virtual technologies in the architectural, engineering, construction and operation industry. The conference is also known for having a unique blend of participants from both academia and industry.

We would like to build on our last year conference success which was held in London, Oct 2013, (www.convr2013.com) and further develop VR research and enterprise topics that will advance the research area and assist in improving efficiency and effectives of the construction industry worldwide. We also will bring a very imaginative research topic which is the application of VR in Islamic architect.

We have a group of leading keynote speakers from industry and academia who will not only cover up to date advances in Virtual Reality and information technology applied to construction processes but will share their construction experiences in the middle-east.

CONVR participants are very loyal to the conference and have attended most of the last thirteen editions. This year we are welcoming numerous first timers from the middle-east and we aim to help them make the most of the conference by introducing them to other participants.

Finally, our overall aim is to ensure all participants leave the conference feeling knowledgeable, inspired and full of new ideas and with many new friends! We look forward to seeing you in the University of Sharjah, Nov, 2014.

Yours faithfully,

Honorary Chair, Prof. Hamid Al-Nuaimiy, Chancellor, University of Sharjah

Chair, Professor Nashwan Dawood, Teesside University

Co chair, Professor Sabah Alkass, University of Sharjah

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KEYNOTE SPEECH I

Prof. Osama Moselhi

Title: Visualization of onsite construction progress using remote sensing and BIM

Abstract: Tracking, trending and progress reporting of onsite construction operations have received considerable attention from practitioners and academics alike ever since the introduction of the earned value management (EVM) method back in 1976 by the United States Department of Defense for progress reporting. The use and applications of this method in management of engineering, procurement and construction projects has been the subject of numerous publications, most notably those produced by the U.S.A. Department of Energy, and National Aeronautics Space Agency and those described in a number of textbooks. This presentation will describe the essential requirement for accurate and reliable utilization of EVM and it will highlight the challenges in its use for reporting periodic progress and for forecasting. The progress made over the last few decades in reporting the estimated earned value, i.e. the budgeted cost of work performed, will be described with a focus on the use of automated site data acquisition technologies for that purpose. This includes the use of global positioning system (GPS), radio-frequency identification (RFIDs), and wireless sensor networks, along with their respective communication protocols. Integrated with these deployed data capturing technologies are BIM (building information modelling) and project schedule to generate 4D dynamic project model that provides useful visualisation capabilities in reporting physical progress onsite. The presentation will also introduce recently developed self-adaptive models and practical guidelines for accurate forecasting of project cost and duration at completion and/or at any given time horizon. Selected set of example project applications will be presented to illustrate the use of the automated site data acquisition technologies described above and to demonstrate the visualisation capabilities achieved using BIM.

Bio: Dr. Moselhi is Professor of Engineering in the Department of Building, Civil and Environmental Engineering at Concordia University. He served as Department Chair and Executive Advisor to the Dean of the Faculty on graduate studies and research and on space planning and appraisal of graduate programs. Since joining Concordia in 1985, after a decade of industry experience, Dr. Moselhi supervised and co-supervised over 80 Masters and Ph.D. graduates, authored and co-authored over 350 scientific publications. His industry experience spans tall buildings, bridges, nuclear power plants, harbour and offshore facilities. He is recipient of numerous honors and awards; including the prestigious CSCE Walter Shanly Award in recognition of *"outstanding contributions to the development and practice of construction engineering in Canada"* and the international Tucker-Hasegawa Award, in recognition of *"individuals in industry or academia who have made a major, sustained contribution to the field of Automation and Robotics in Construction"*. Dr. Moselhi served as international consultant on academic affairs and on construction projects in Canada, USA, and the Middle East. His research interest encompasses planning, procurement, resource allocation, tracking and control of construction projects, with a focus on risk management, productivity analysis, management of construction claims and development of decision support systems embracing information technology, remote sensing, web-enabling and spatial technologies.

KEYNOTE SPEECH II

Dr. Rene Schumann, Managing Director at HOCHTIEF ViCon Qatar

Title: BIM and VR Technologies Implementations in the Middle East

Abstract:

Bio: Rene Schumann is currently the Managing Director of HOCHTIEF ViCon in Qatar. After finalizing his studies with a degree in Structural Engineering and certification as a Project Manager in Germany, René started his career at HOCHTIEF in 1998. Rene supported HOCHTIEF's efforts to implement virtual construction techniques, an endeavor which eventually led to the establishment of HOCHTIEF ViCon in 2007. As ViCon's Head of Operations from day one, he has advised clients throughout the industry. René is one of the original creators of the ViCon Method, and the driving force behind ViCon's focus on pragmatism and client benefits. In 2009, HOCHTIEF ViCon founded a subsidiary in Qatar, where Rene took on the responsibility of Managing Director. Through his close relationships with the construction community, and work on high profile projects, René has lead the team in Qatar to a prominent position in the Qatari market. Rene is responsible for all international operations of HOCHTIEF ViCon.

KEYNOTE SPEECH III

Dr. Charles Woodward, Research Professor at VTT Technical Research Centre of Finland

Title: Augmented Reality for AEC – Pioneering Works, Past, Present and Future

Abstract: In his keynote Woodward gives an overview on VTT's pioneering work in AR applications for the AEC sector since the early 2000's. Some of their world first applications include: applying mobile AR for architectural visualization; implementing internet AR webcam at construction site; employing Google Earth maps and GPS for mobile AR visualization; combining mobile AR visualization with 4D BIMs at construction site; and employing mobile AR visualization in various real land use cases. Related applications include implementations of augmented scale models, augmented interior design system, visualization of past buildings in historical settings, and mixed reality interaction with virtual worlds. Woodward's recent research addresses mobile AR and BIM applications for indoors applications such as building maintenance and navigation. Further AR applications and technology are described for markerless feature and point cloud based 3D tracking and photorealistic visualization.

Bio: Dr. Charles Woodward received his Ph.D. degree in Computer Science at Helsinki University of Technology in 1990, where Woodward and his team pioneered in developing 3D modeling and ray tracing visualisation for industrial designers. The years 1991-2000 Woodward headed his spin-off company DeskArtes Oy in international software business, with product lines for 3D CAID and Rapid Prototyping. After joining VTT in 2001, Woodward was nominated Research Professor of Multimedia technology in 2004, and Research Professor in Augmented and Virtual Reality 2010. Throughout the last decade, Woodward and his team at VTT have produced world leading solutions for various Augmented Reality (AR) application fields, including media and marketing, entertainment and games, interior design, industrial applications, and collaborative telepresence interaction. Woodward's special research focus is on Augmented and Mixed Reality application in the AEC sector (Architecture, Engineering and Construction).

KEYNOTE SPEECH IV

Prof. R. Raymond Issa, University of Florida

Title: Enhancing special and temporal cognitive ability through augmented reality

Abstract: It is essential to provide the future industry workforce with the education to fully develop their abilities to effectively solve construction problems in order to reach high productivity levels. In particular, the ability of construction engineering and management (CEM) students to solve problems is hindered by the lack of exposure to construction processes on the job-site, which results in their lack of understanding of the dynamic complex spatial constraints (e.g., how construction products are related to one another in particular contextual space) and the temporal constraints (e.g., the dependencies for coordinating subcontractors' processes). Spatial-temporal-constraint problems pervade projects during the construction phase, students' full understanding of the construction processes helps them in solving construction management problems and also enables them to significantly improve productivity levels.

This presentation explores how the use of Augmented Reality Technology (ART) in the classroom provides educators with an instructional mechanism to virtually incorporate jobsite visits through the perception of the reality via the combination of two layers (the real environment and computer-generated information). ART enhances the physical, real-world environment through a computer-generated sensory input. For example, ART enables CM students to enhance their perception of the jobsite and, more importantly, it also allows them unlimited access to otherwise limited opportunities to participate in jobsite experiences.

Bio: Professor Raymond Issa is currently the UF Research Foundation and Holland Professor in the University of Florida's Rinker School of Construction Management and Director of the Center for Advanced Construction Information modeling and the Building Information Modeling (BIM) Visualization Laboratory. Raymond has completed over $7 million in information technology related research and he has served as Chair on over 250 Masters Committees and over 45 Ph.D. Committees, Raymond has also authored over 300 journal and conference proceeding articles and scientific reports.

Raymond has received University, College and School level recognition for excellence in research (UF Research Foundation Professor (2)), teaching, and academic advising (Academic Advisor of the Year; PHD Advisor/Mentor (2)). Raymond also serves on the Board of Directors of various industry and professional organizations, including the National Center for Construction Education and Research and the International Society for Computing in Civil and Building Engineering (ISCCBE). He has served as chair of the American Society of Civil Engineers (ASCE) Technical Council on Computing and Information Technology and on various other ASCE technical committees. He also serves as an UPADI Vice-President for North America. Raymond was recently awarded the 2012 ASCE Computing in Civil Engineering Award and was elected to the Pan American Engineering Academy. In publications related work, Raymond is currently the Senior Associate Editor of the ASCE Journal of Computing in Civil Engineering and editor of two ASCE monographs Ontology in the AEC domain: A decade of research and developments and Building Information Modeling: Applications and Practices in the AEC Industry.

KEYNOTE SPEECH V

Prof. Ghassan Aouad, Vice president for Academic Affairs at Gulf University for Science and Technology Kuwait & President of The Chartered Institute of Building

Title: Advanced IT and the readiness of technology in the Gulf region

Abstract: In this lecture, an overview of advanced IT in construction with particular emphasis on the gulf region will demonstrate that this region is embracing such technologies. The competitiveness of this region through the use of advanced IT such as VR, BIM, etc will be discussed relying heavily on the competitiveness reports of the World Economic Forum published between 2009 and 2014. A series of recommendations will be suggested of how Advanced IT can help in the further improvement of these competitiveness indicators. Some practical examples from previous research will be demonstrated in order to assist the construction industry in the Gulf region benefits from international experiences in the area of technology readiness. This lecture will conclude with a map for the future of advanced IT in construction.

Bio: I am currently Vice President for Academic Affairs at Gulf University for Science and Technology and before this I was President of the University of Wollongong Dubai.

Before moving to the Middle East, I was at the University of Salford in the UK. During my 20 years at the University of Salford, I have held several roles, including Pro Vice Chancellor for Research and Innovation, Dean of the College of Science & Technology, Dean of the Faculty of Business, Law & the Built Environment, Director of the Research Institute of the Built & Human Environment and Head of School of Construction & Property Management now the School of the Built Environment. I am currently a visiting professor at the University.

I successfully supervised 24 PhD students, externally examined 52 PhD students, authored 3 major research books and co-authored one book, generated more than £10M in research funding as Principal Investigator and £8M as Co-Investigator, published 92 papers in top rated refereed journals, delivered more than 50 keynote speeches and invited lectures, and presented my work in more than 40 countries. I am named as one of the top ten academic leaders shaping executive education in the Middle East by the Middle East Economic Digest.

KEYNOTE SPEECH VI

Prof. John Messner, Charles and Elinor Matts Professor of Architectural Engineering at Pennsylvania State University, USA

Title: Business case for VR and BIM

Abstract: Virtual Reality (VR) is certainly not new, but the broad adoption of Building Information Modelling has redefined the value proposition for broad implementation of VR in the Construction Industry. To date, many implementations of VR have focused on isolated case studies or experimental research implementations. But this is changing, quickly. Since Building Information Modelling (BIM) is becoming a standard process for many projects, the content to quickly develop valuable virtual reality experiences for project teams is becoming readily available. This presentation will explore the current best in class use cases for VR, along with approaches that can be used to define the value proposition. The future use cases for VR that will have profound impacts on the efficiency and effectiveness for delivering facilities will also be explored.

Bio: Prof. Messner is a Professor of Architectural Engineering at Penn State and leads the Building Energy Informatics area of the Consortium for Building Energy Innovation. He specializes in Building Information Modelling (BIM) and virtual prototyping research. As the Director of the Computer Integrated Construction (CIC) Research Program, he led the development of the BIM Planning Guide for Facility Owners, and the previously completed BIM Project Execution Planning Guide. He has received National Science Foundation support to investigate the application of advanced visualization in the AEC Industry and engineering education. As a part of these grants, he led the development of two Immersive Construction (ICon) Labs, which are large, 3 screen immersive display systems for visualizing design, construction and operations information. He has also led the development of the Virtual Construction Simulator simulation game. He previously worked as a project manager on various construction projects for a large general contractor and an infrastructure development company. He has taught courses in virtual prototyping; BIM; strategic management in construction; international construction; and project management at Penn State.

PART I: BIM & VR: Site Applications

AN ENERGY MODEL FOR SUSTAINABLE DECISION-MAKING IN ROAD CONSTRUCTION PROJECTS[1]

Jan Krantz, ***Weizhuo Lu***, ***Tim Johansson*** & ***Thomas Olofsson***
Luleå University of Technology, Sweden.

ABSTRACT: *Road construction operations often require considerable amounts of energy in the form of fossil fuels, thus generating substantial greenhouse gas (GHG) emissions. While fuel efficiency of the heavy construction equipment is extensively studied, limited attention is given to how the construction process can be planned in order to reduce energy use and GHG-emissions. In this study a conceptual model is proposed for the assessment of energy use and GHG-emission on-site at road construction projects. The model is applied to a road construction project to evaluate production alternatives in the early planning stages of the project. As a result the most favorable alternative in terms of energy use and GHG-emissions could be selected during the construction phase. This demonstrates the model's ability to quantify environmental effects and energy use of different production alternatives.*

KEYWORDS: *Earthworks; Energy estimation; Greenhouse gas emissions.*

❖ INTRODUCTION AND BACKGROUND

Road construction generally requires extensive earthworks operations such as excavations, hauling, and depositing of materials as well as crushing of rock. These operations require large and energy intensive equipment and thus generate considerable amounts of greenhouse gas (GHG) emissions (Apif M, Phil 2013). (Stripple 2001) estimated that the amount of fuel needed to construct a road is about 5% of the total fuel consumption of all traffic, of 5 000 vehicles per day, using the road during its expected lifetime of 40 years. Energy efficiency, as a measure for mitigating GHG-emissions, has become one of the most important centers of attention for the Swedish Transport Administration (STA). This includes the construction processes of transportation infrastructure (Trafikverket 2012). Although the potential for reducing GHG-emissions and the use of energy in earthworks processes is high, not all important aspects have been investigated (Kim et al. 2011). In contemporary research, significant attention is given to measuring and assessing the emissions per heavy equipment (Mawlana et al. 2012, Yanowitz, McCormick & Graboski 2000, Abolhasani et al. 2008, Frey, Rasdorf & Lewis 2010). A study by (Melanta, Miller-Hooks & Avetisyan 2013) provided a comprehensive project-level estimation tool that take into account material production and the effects of absorbed CO_2 in forests and organic soils during deforestation and clearing or reforestation efforts. The performance of construction projects is mainly assessed in terms of time, costs and quality with limited attention to emissions and other environmental aspects (Gangolells et al. 2009, Kenley, Harfield 2011). These are aspects that might help reducing equipment operation time, mass hauling distances, and the number of engines used (Ahn et al. 2013). A stronger focus to reduce GHG-emissions in the project planning stage through environmental assessments of alternative designs and production methods is therefore important (Kim et al. 2011). Proposed in this study is a conceptual model for quantifying the energy use and GHG-emissions for on-site activities in road construction projects. The model is used in a case study of two planned road projects located in the city of Kiruna in Sweden. The results of the case study demonstrate the model's ability to quantify the environmental effects and energy use of different production alternatives.

Earthworks operations and estimation of energy use

Road construction projects consist of major earthmoving activities both in terms of material quantities managed and distances that the material is moved. Cutting and filling are the processes of excavating materials at cuts and depositing materials at fills along the road line. Cuts and fills might consist of different materials, which can be categorized and used for different purposes. Common cut-materials include rock, organic and inorganic soils where the rock can be used in fills to stabilize the ground conditions or can be crushed to be used as fill materials in the base course, the sub base or in asphalt or concrete surface layers. Minimizing mass hauling distances is one of

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the goals in the planning of earthworks activities. Different mathematical techniques such as linear programming have been proposed for minimization of mass haul distances (Easa 1988). However, there are often other important factors to consider in the planning and scheduling of earthworks activities (Askew et al. 2002). The NONROAD-model by US EPA is a comprehensive tool for estimating various emissions of large populations of vehicles and equipment (EPA 2005). The model lacks information with regard to construction project-level emissions although parts of the model are implemented in other models and tools designed for construction projects. The Inventory Model of Off-Road Equipment by California Air Resources Board is another model that estimates fuel consumption and emissions of NO_x, particulate matters and hydrocarbons from populations of equipment in California (California Air Resources Board 2011). A comprehensive tool for estimating emissions of GHG in road construction projects was proposed by (Miller-Hooks, Melanta & and Avetisyan 2010, Melanta, Miller-Hooks & Avetisyan 2013). It encompasses effects of carbon-sequestration capacity lost when woods and soils are removed as well as the effects of reforestation efforts. While being a comprehensive tool it lacks in detail especially in how the emissions from equipment is assessed or connected to project specific quantities. A more detailed but less comprehensive tool was proposed by (Apif M, Phil 2013). The method uses a multiple linear regression (MLR) method to model productivity of some simple earthworks operations based on productivity data from RSMeans. The productivity model is then used as input to model energy use and emissions.

PROPOSED CONCEPTUAL MODEL

The proposed conceptual energy model, shown in Fig. 1.is designed to make sense of how the energy use and the corresponding GHG-emissions at road construction sites can be calculated or estimated.

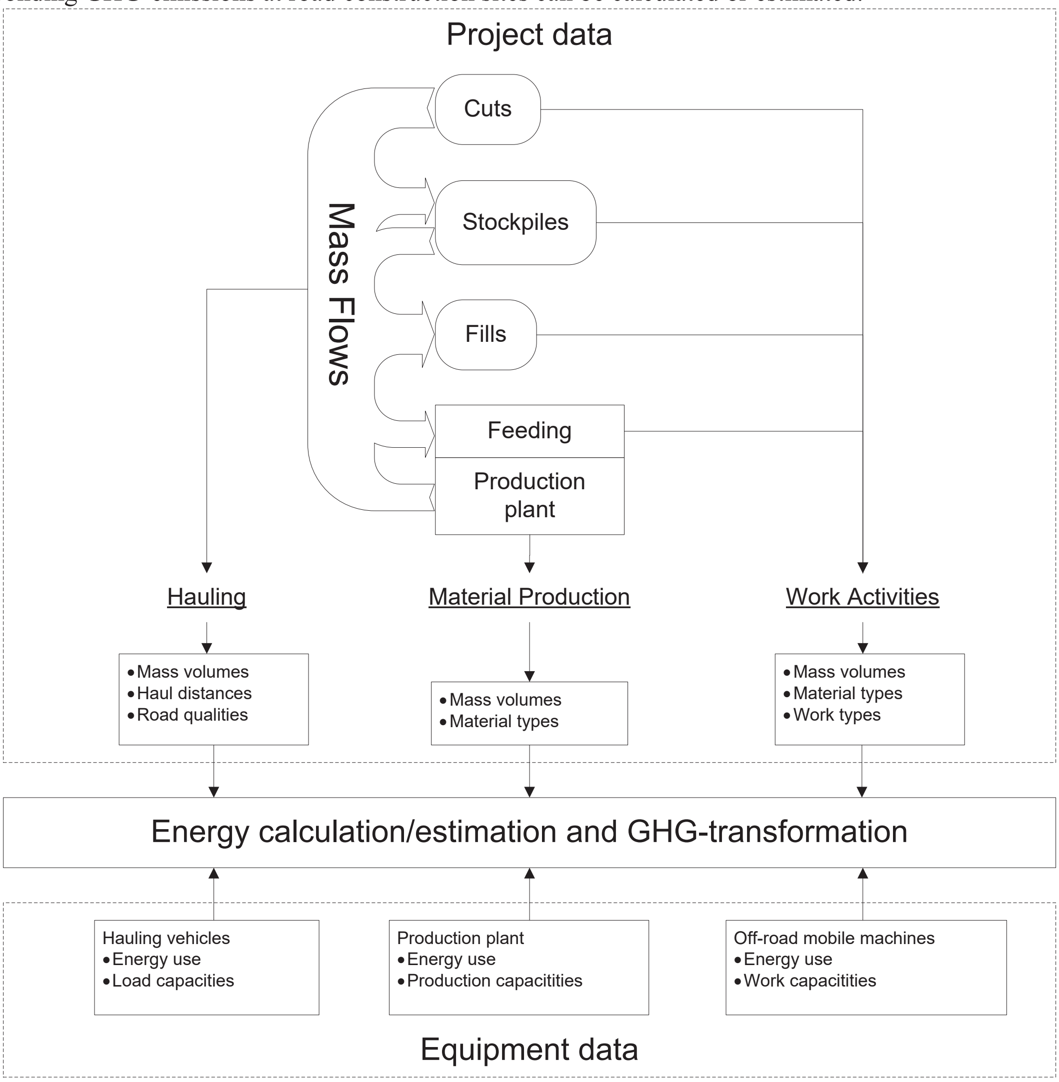

Fig. 1 The conceptual energy model.

The energy-consuming activities at the construction site are categorized into "Hauling", "Material Production" and

"Work Activities". "Hauling" is the process of moving material between cuts, fills, material production sites and various stockpiles using specific hauling vehicles such as articulated haulers and dump trucks sometimes towing trailers. "Material Production" consists of large scale processing and production of materials and includes for example crushing plants, concreting plants and asphalt plants. "Work Activities" include cutting, filling, loading and loosening etc. This type of work is done using off-road mobile machines such as bulldozers, excavators, drill rigs, wheel loaders etc. Included in "Work Activities" is also shorter moving of materials that sometimes happens with wheel loaders or bulldozers. These categories are connected to some project specific quantifiable data which include hauling distances, mass volumes and material types, etc. The project data is a quantification of the tasks in the road project that are needed to make reliable calculations or estimations of the energy use associated with the road project. The equipment used for finishing these tasks has a different type of data namely the equipment data. This includes for example the load- and work capacities and the energy use of the equipment etc. This data combined with appropriate energy calculation methods are needed in order to calculate the total energy use in a road construction project.

CASE STUDY

To evaluate the practical applicability of the proposed model, a case study is made. The case study helps reveal some potential problems that can arise with the practical application and whether it can affect decision-making with respect to GHG-emissions and energy use. The case study consists of two new roads in Kiruna Municipality in the north of Sweden. These road projects are the "E10" and "Road 870" shown in Fig. 2.

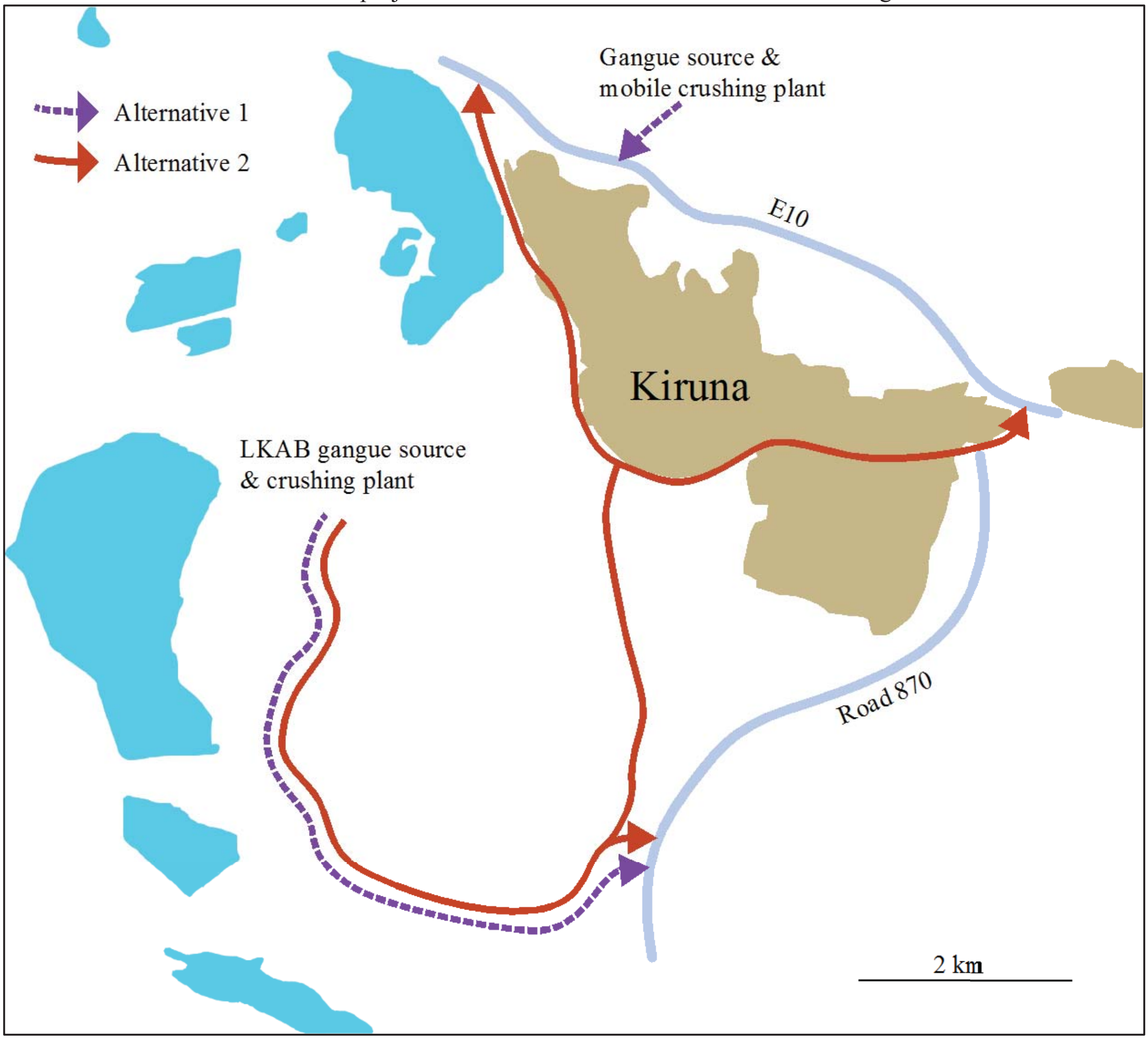

Fig. 2 The hauling routes for the crushed aggregates in each alternative.

The case study was made in the planning stage of the road projects when corridors had been decided and the road locations were being decided in detail. The STA, who were the client in the projects, wanted to compare two production alternatives from an energy perspective. In "Alternative 1" some of the crushed aggregates used in the road were intended to be produced locally near the road line. While in "Alternative 2" all the crushed aggregates were produced by the mining company LKAB in the city. Table. 1 shows a detailed comparison of the alternatives studied in this case study.

Table. 1 Overview of the alternatives in the case study

	Alternative 1	Alternative 2
"E10"		
Cut & Fill	handled in road line	handled in road line
Excess earth cut	not accounted for	not accounted for
Rock cut	crushed and used in road line	hauled to nearby disposal area
Subbase	produced from rock cut and nearby gaunge source	rovided by LKAB
Base course	produced from rock cut and nearby gaunge source	provided by LKAB
Energy source for crushing	diesel driven electric generator	electricity from the grid
"Road 870"		
Cut & Fill	handled in road line	handled in road line
Excess earth cut	not accounted for	not accounted for
Rock cut	none	none
Subbase	provided by LKAB	provided by LKAB
base course	provided by LKAB	provided by LKAB
Energy source for crushing	electricity from the grid	electricity from the grid

The STA expected that producing the crushed aggregates near the road line as it is done in Alternative 1 would require shorter hauls and therefore lower energy use and emissions of GHG instead of having the LKAB provide the material which is common practice in Kiruna. In the case study the construction of the subgrade, sub base and base course layers were considered. This included the mass hauls, crushing of aggregates and acquisition and disposal of some material off-site.

DATA COLLECTION, ASSUMPTIONS, AND CALCULATIONS

Because of the scale of the road projects the acquisition of data has been extensive. Also, since the projects were at an early planning stage, not all of the necessary data has been available. Therefore, some assumptions and manual preprocessing of unrefined data have been necessary to complete the study. Beside a detailed description of the different alternatives the STA contributed with a map, a bill of quantities, some details of the work activities included in the projects and other project specific information. This data had to be preprocessed in the mass-haul planning software DynaRoad to create a mass-haul plan which essentially provides information of hauling distances, types and quantities of materials hauled, worked and produced. The DynaRoad software implements linear programming methods to minimize the hauling distances. To account for swelling or shrinking of material the common mass states of Bank Cubic Meters (BCM), Loose Cubic Meters (LCM), and Compacted Cubic Meters, were used. The correction factors of the applicable materials in the case study are as follows:

Material	BCM	LCM	CCM	Tonnes
Rock	1	-	1.45	2.7
Earth	1	1.2	-	2
Subbase	-	-	1	2.15
Base Course	-	-	1	2.25

Hauling of earth is calculated based on the load capacity in terms of volume while other materials are based on their mass and this is assumed to be true for both trucks and articulated haulers. The STA provided information about the likely equipment that would be used during the construction of the road. Based on this information some data about load capacities, work capacities, power rating, and other necessary data was found. If data about certain machines could not be found, some equivalent machines were assumed instead. A total of four different energy calculation formulas were used. "Hauling" was divided between two formulas, one distance-based for trucks and trailers and one time-based for articulated haulers. "Material production" in the form of crushing of aggregates uses an elementary relationship while the "Work activities" with off-road mobile machines uses a formula based on the rated power, average load factor, the brake-specific fuel consumption and the activity of the machine. Additional details of this case study can be found in (Krantz 2013).

Hauling with trucks and trailers

To account for the fuel consumption of hauling by trucks with trailers Eq. (1) is used. Trucks with trailers are used for hauls that part of the way use public roads. The independent variables in the equation are the hauling distances, load capacities of the trucks, total masses, and the fuel use per km of the trucks (Nätverket för Transporter och Miljön (NTM) 2006).

$$F_{truck} = \sum_i (L_t / L_c * 2 * T_d * F_c)_i \qquad \begin{cases} i = \text{all truck configurat ions in the project} \\ F_{truck} = \text{total fuel use of trucks} \\ L_t = \text{masses hauled} \\ L_c = \text{load capacity of vehicle} \\ T_d = \text{hauling distance} \\ F_c = \text{fuel consumptionof vehicle} \end{cases} \qquad (1)$$

Furthermore a correction factor of 1.44 was used to account for the extra fuel use of the truck at the instances when they run on dirt roads (Abelson 1973). The truck type assumed was a 3-axle truck with a 4-axle trailer with a load capacity of 30.8 m^3 or 40 tonnes and fuel consumption of 0.58 liters / km.

Hauling using articulated haulers

Articulated haulers aren't allowed on public roads and thereby can only be used within the road lines that are built and the road connection to the LKAB area from "Road 870". The fuel consumption from articulated haulers is calculated with Eq. (2). The equation is based on hauling time which is dependent on the hauling distances as is also the case in Eq. (1).

$$F_{hauler} = \sum_i (L_t / L_c * C_t * F_c)_i \qquad \begin{cases} i = \text{all articulated hauler configurat ions in the project} \\ F_{hauler} = \text{total fuel use of articulated haulers} \\ L_t = \text{masses hauled} \\ L_c = \text{load capacity of vehicle} \\ C_t = \text{cycle time} \\ F_c = \text{fuel consumption of vehicle} \end{cases} \qquad (2)$$

The calculation method is explained in the Caterpillar Performance Handbook (Caterpillar Inc. 2012). A Volvo A40, with a load capacity of 22.2 m^3 or 36 tonnes, was assumed as the type of articulated hauler used, but to be able to calculate the cycle times and fuel use, a Caterpillar 740 Tier 3 was assumed as an equivalent vehicle to the A40. The following assumptions regarding the cycle times were made: loading time = 2.5 min; dumping time = 0.5 min; full loaded speed = 20 km/h; empty speed = 28 km/h. The fuel consumption of the vehicle is assumed to be 20 l/h.

Material production with crushing plants

The only type of material production accounted for in this study is the production of base course and sub base through crushing. Eq. (3) shows the basic relationship used for the energy use of crushing.

$$E_{crushing} = \sum_i (E_c * M_t)_i \qquad \begin{cases} i = \text{all crushing configurat ions in the project} \\ E_{crushing} = \text{total electricity use of crushing} \\ E_t = \text{electricity consumption of crushing plant} \\ L_c = \text{masses crushed} \end{cases} \qquad (3)$$

The crushing plant assumed is based on the use of a Sandvik HJ3800 crusher with an estimated electricity consumption of 5.54 kWh/t of produced end material. This includes the fact that different fractions need to be crushed several times the number of times the material needs to pass the crusher is assumed to be 2.675. The electricity sources of the crushing plants are either the electric grid or a diesel driven electric generator depending on when which is applicable. The diesel driven electric generator is assumed to have an efficiency of 38% in its generation of electricity.

Work activities with off-road mobile machines

To calculate the fuel use of the off-road mobile machines Eq. (4) is used.

$$F_{offroad} = \sum_i (A * P * L_f * B_e)_i \quad \begin{cases} i = \text{all articulated hauler configurations in the project} \\ F_{offroad} = \text{total fuel use of off-road mobile machines} \\ A = \text{activity of the machine} \\ P = \text{rated power of the machine} \\ L_d = \text{average load factor} \\ B_e = \text{brake-specific fuel consumption} \end{cases} \quad (4)$$

The rated power (P) of the machine is a straightforward once a machine is selected. The L_f for excavator activities is based on research by Persson and Kindblom (Persson, Kindblom 1999) while the remaining load factors come from (EPA 2010). The B_e-values are based on work by Lindgren (Lindgren 2007) and are a function of the rated power. The activity is a function of the capacity of the machine performing a specific task which is partly assumed and partly read from capacity diagrams. Activity (A) is also a function of the quantity of masses worked or the surface area worked which is predominantly the case when compacting or leveling. In Table. 2 the mass quantity based activities can be seen, note that the brake-specific fuel consumption (B_e) is 0.254 kg/kWh for all of these machines.

Table. 2 Description of the mass-based activities with their corresponding machines.

Machine	L_f	P (kW)	Capacity (BCM/h)	Description
Excavator 45 tons	0.40	250	175	Loosening earth cuts and loading to hauling vehicle
Bulldozer CAT D7	0.58	175	150	Recieving loosened earth and spreading to fill
Drill Rig Sandvik DX780	0.43	151	100	Loosening rock cut
Excavator 45 tons	0.40	250	130	Loading loosened rock to hauling vehicle
Bulldozer CAT D7	0.58	175	150	Recieving rock and spreading it at a rock fill
Loader CAT 980	0.48	260	250	Loading loosened rock to crushing plant
Loader CAT 980	0.48	260	250	Loading crushed aggregates to hauling vehicle
Bulldozer CAT D7	0.58	175	150	Recieving subbase and spreading it

The surface based activities and their corresponding machines can be seen in Table. 3. The total road length in the project is 16.96 km and it's estimated that in the road roller needs 18 trips or 9 round trips on the roads to compact each layer. The motor grader is assumed to need 9 trips in total or 4.5 round trips to level the base course.

Table. 3. Description of the surface-based activities with their corresponding machines.

Machine	L_f	P (kW)	B_e	Speed (m/h)	# trips	Description
Road Roller	0.59	110	0.26	500	18	Compacting earth fills
Road Roller	0.59	110	0.26	500	18	Compacting subbase
Road Roller	0.59	110	0.26	500	18	Compacting base course
Motor Grader	0.59	159	0.254	5000	9	Leveling base course

Transformation to GHG-emissions

The energy use gives rise to GHG-emissions in the form of CO_2 depending on the type of energy used. In the studied road projects the energy types are fuel (diesel) and electricity. To account for the CO_2-emissions caused by electricity consumption the average Swedish emissions are assumed and equals to 0.02 kg CO_2/kWh (Svensk Energi 2014). The diesel combustion is assumed to cause emissions of 3.22 kg CO_2 per kg diesel combusted.

RESULTS

Alternative 2, where all crushed aggregates are provided by the LKAB, has considerably longer hauling distances compared to Alternative 1, where some of the crushed aggregates are produced from nearby gangue. Although the hauling distances in Alternative 2 are 142% longer than in Alternative 1, the corresponding diesel use is only 69%

higher. The crushing of materials in Alternative 2 uses 144% more electricity than in Alternative 1, but Alternative 1 has considerable diesel consumption as a result of the crushing next to the road which runs with a diesel driven electric generator. For the work activities both alternatives require the same amount of diesel since the work activities are the same for each alternative. For the entire project, Alternative 1 requires 63% more diesel than Alternative 2. However, Alternative 2 uses 144% more electricity than Alternative 1. The total CO_2-emissions, based on both the diesel- and electricity consumption, is 59% higher in Alternative 1 than in Alternative 2.

Table. 4 Summary of the results from the case study.

	Unit	Alternative 1	Alternative 2
Hauling			
average distance	(m)	3 664	8 851
masses hauled	(t)	1 753 171	1 753 171
diesel use	(kg)	290 955	491 573
Material production			
masses crushed	(t)	1 100 393	1 100 393
diesel use	(kg)	803 980	
electricity use	(kWh)	2 494 210	6 093 151
Work Activities			
diesel use	(kg)	459 714	459 714
Total			
diesel use	(kg)	1 554 649	951 288
electricity use	(kWh)	2 494 210	6 093 151
CO_2-emissions	(kg)	5 055 855	3 185 010

DISCUSSION AND CONCLUSIONS

The conceptual energy model turned out to be useful as a decision-making tool as the most favorable alternative in the case study was identified and implemented later in the road project. Implementing the model at an early planning stage in the road construction project can offer both challenges and opportunities. The challenge is to acquire reliable data since not all data has been produced at such an early stage. However since the case study involves the comparison of certain alternatives one might suspect that many of the inaccuracies cancel out. The opportunities therefore seem extra strong when the tool is used for comparisons between alternatives in the early planning stages as large scale changes are easier to implement. This study has both a theoretical and a practical contribution. The theoretical contribution is the conceptual energy model which is helpful for getting an understanding of how the energy use in a road construction project can be understood and the main types of data needed to calculate the energy use. The practical contribution is the application of the model to real road projects. This helps reveal a method of how the conceptual energy model practically can be implemented and the constructor in this case used the findings to adapt their production method.

ACKNOWLEDGEMENTS

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BEYOND CLASSIC MODELS—DESIGN AND DEVELOPMENT OF A COMPREHENSIVE EARTHMOVING SIMULATOR[1]

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ABSTRACT: *Modeling and simulation of construction operations has long been used as an effective research tool, and sometimes as a practical decision-making aid. The scope of most simulation models of construction operations is usually dictated by the capacity of a single developer, and model life span is therefore usually short. In this paper, we present a different take on classic earthmoving operation simulation. We present the development process of a comprehensive earthmoving simulator that spans a much wider scope than traditional simulators. We describe the overall structure and components of the simulator focusing on the development process, which involved collaboration between seven developers over a four-month time period. We also illustrate the work of two components of the simulator that deal with setting simulation scenarios, fuel consumption and environmental emissions, and 3D visualization as examples.*

KEYWORDS: *Earthmoving, Distributed Simulation, Visualization, High Level Architecture (HLA)*

❖ INTRODUCTION

Earthmoving for construction and mining operations is a repetitive process that involves many elements and resources (e.g. soil, haulers, and loaders), and their interaction affects the overall performance of the process. Earthmoving has been a classic subject of simulation modeling research in construction, and many earthmoving simulators have been developed with different analytical representations and objectives that mostly revolve around optimization of fleet composition and maximizing equipment utilization. Motivated by the large earthmoving operations required for oil-sand projects in the province of Alberta, Canada, a team of researchers have begun developing a comprehensive earthmoving simulator that encompasses many influencing factors to generate realistic operation behaviors. These factors relate to road layout, road materials, road maintenance, equipment specifications, equipment maintenance, fleet composition, and weather parameters. The simulator generates the process behaviors through the integration of six different simulation components developed by seven developers in parallel. The components (federates) are integrated at run time through the High Level Architecture (HLA) standards. These components are: 1) a controller that works as a dashboard for scenario definition and analysis, and also simulates fuel consumption and Carbon Monoxide (CO) and Nitrogen Oxide (NOx) emissions, 2) a mover simulator for simulating hauler-road interactions and behaviors, 3) a loader simulator for simulating the loading and dumping process, including loader movements and loader-soil interactions, 4) an equipment breakdown and maintenance simulator, 5) a weather parameters simulator, and 6) a 3D visualizer. The aim of this paper is to describe the process to develop the simulator (federation). It also describes the different components at a high level, and explains the controller and 3D visualization components in more detail.

BACKGROUND

Earthmoving

Earthmoving operations are affected by many factors including road layout, road material, fleet characteristics and fleet operation plan, fleet efficiency and weather conditions. Many studies have been conducted in the construction domain on modeling and simulating earthmoving operations, with different purposes. Most studies focus on fleet optimization. Examples of these include work by Hajjar and AbouRizk (1996 and 1998), Alkass, Moslmani, and Al-Hussien (2003), Hsiao, Lin, Wu, and Cheng (2011), Cheng et al. (2011), Zhang (2008), and Marzouk and Moselhi (2008). Some simulators have been developed specifically for training purposes, such as Ni et al. (2013), and González et al. (2009). Other work aimed at integrating simulation with real time data for tracking and control purposes, such as the work of Alshibani and Moselhi (2012), and Vahdatikhaki and Hammad (2014).

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Other researchers investigated performance of earthmoving operations. As an example, Joseph and Szymanski (2013) identified fuel usage and emissions as an emerging industry concern, in response to global warming. The researchers argued "roads make loads" and stated controlling road surfaces' rolling resistance would result in desired target of fuel burning quality and emissions. Fuel consumption is affected by a number of factors such as speed, truck capacity and road conditions, and the best way to track fuel consumption is to obtain data from the actual operation; however, the availability of such data is limited. Therefore, this study quantifies truck's fuel consumption throughout the simulation considering the factors identified above.

Distributed simulation

Due to the increasing complexity of simulating operations, a distributed simulation approach was introduced. Advantages of a distributed simulation approach include scalability and a reduction in execution time for large models by using and linking multiple computers scattered geographically (Wilcox, Burger, and Hoare 2000). High Level Architecture (HLA) is a well-known and accepted standard for distributed interactive simulations that aims to promote interoperability and the reuse of models in different environments (IEEE 1998). The main components of HLA are interface specification, the Object Model Template (OMT) and HLA rules. The interface specification describes all the services provided to the federate through the Run Time Infrastructure (RTI) and vice versa (IEEE1516.1), whereas the RTI is software that provides services such as communication, synchronization points and data exchange that are used by the federate for HLA simulation. The OMT describes how the HLA object-modeling information is documented (IEEE 1516.2). HLA has three types of object models: Federation Object Model (FOM), Simulation Object Model (SOM) and Management Object Model (MOM). The FOM describes the data used by the RTI, the MOM defines the entities and interactions in federation execution, and the SOM contains the simulation functionality for a federate such as the object types, attributes and interactions. The rules describe HLA principles for both the federation and federate, and they must be enforced to be regarded as HLA. For instance, federations require FOM in the OMT format, while federates require documentation of their public information in their SOM (IEEE 1516).

Earthmoving operation process is a good candidate for distributed simulation, as it can be decomposed into separate components (e.g. mine, road, and weather components). These components can communicate together using HLA standards to simulate the earthmoving operation. Therefore, this approach has been selected in this study.

Virtual reality

Virtual Reality (VR) animations require information about an operation and its surrounding environment. That information can also be used for 3D visualization. Visual simulation is a core planning and analysis tool for engineering processes as it uses virtual-computer-generated resources to create a sense of dynamism, thereby allowing experimentation without committing real resources. This allows decision makers to reduce project uncertainties and assists them in coping with more challenging tasks. However, applying visualization technique requires programming efforts that include developing a user interface, which requires computer graphic knowledge, selection of Application Programming Interface (API), coding models/algorithms, etc.

Al-Hussien et al. (2006) presented a tower crane case study that used MAXSCRIPT, Autodesk 3D's Max scripting language, to integrate with SimAnim, which is a special-purpose simulation system for crane operations. However, after applying the same approach for a complex residential tilt-up-panel structure using certain crane selection algorithms and spreadsheet optimization, Manrique et al. (2007) argued that using this approach could be a tedious task, and the approach lacks efficiency.

Kamat and Martinez (2005) proposed a tool, ViTerra, to represent a construction site in an animated fashion using existing topographical and aerial data. Zhong et al. (2004) used Geographic Information System in their proposed tool, GVSS (GIS-based visual simulation system) to detect logic errors in simulation models. They applied GVSS's capabilities of planning, visualizing and querying to a hydroelectric project (concrete dam construction process). Zhang et al. (2012) used the HLA standards to integrate discrete event simulation with computer visualization and graphical information technologies. The proposed distributed simulation visualization framework (DSVF) used the Construction Synthetic Environment (COSYE) framework to build federates for visualizing tunnel construction. The study concluded that visualization federates would improve the understanding of simulation results. In this study, a visualizer component has been added as a separate federate to animate the earthmoving operation, as explained later.

DESIGN AND DEVELOPMENT PROCESS OF THE EARTHMOVING SIMULATOR

Development cycles

Development of simulation models in general is not a linear process, but rather, a cyclic one that moves between scope definition, implementation, testing, validation, and accreditation steps in a spiral fashion. Collaborative and distributed development requires more coordination between different developers, and hence, it is more challenging to move between these different steps.

The development of the earthmoving simulator progressed according to the following steps, in cycles, each of which was one to two weeks long: 1) define scope; 2) identify mathematical models from literature; 3) define object models for the individual simulation components (SOM); 4) define overall object model for collaborative simulation (FOM); 5) implement components based on defined scope and available mathematical models; 6) test, verify, and validate components individually; 7) run the components collaboratively, test and verify; 8) expand scope and start another cycle.

Objective, scope, and developers responsibilities

The main objective of the simulator is to provide a comprehensive platform for simulating earthmoving operations that can support a wide range of experimentation scenarios, and incorporate, in an integrated way, the effects of variables related to road layout, road material, road maintenance, fleet composition, equipment specifications, equipment breakdown and maintenance, haul material specifications, and weather parameters. In other words, the aim is to create a detailed virtual environment of earthmoving operations that incorporates as much of the "known" relations between operation's variables as possible, and can serve as a test bed for different decisions and/or predictions.

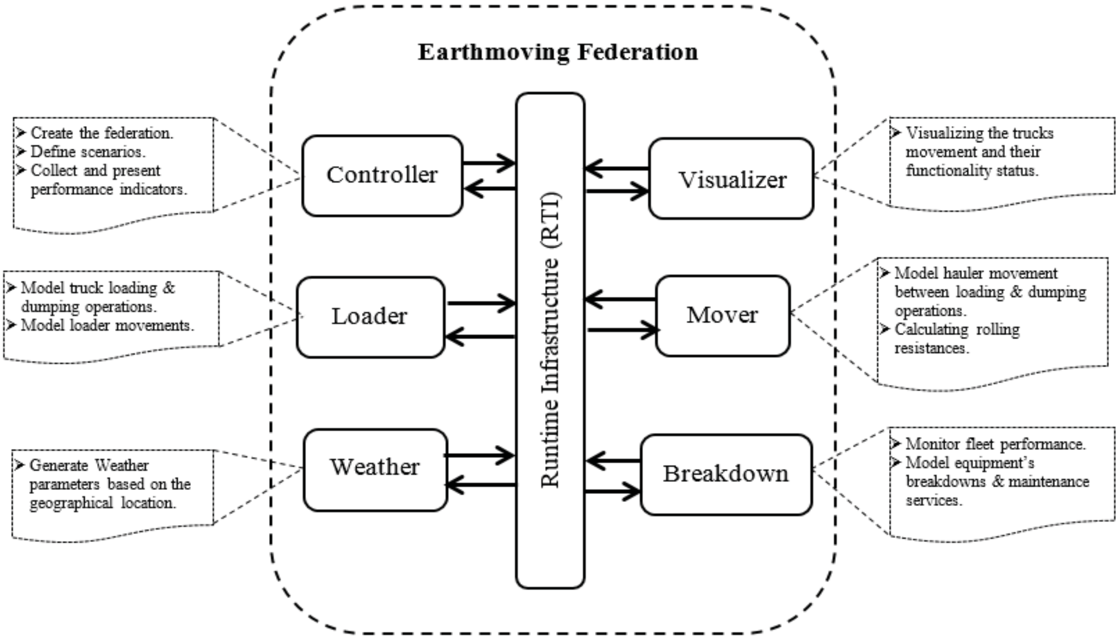


Fig. 1: Federation structure

The scope of the development was broken down between seven developers. The developers were graduate students with previous backgrounds in discrete event simulation and at least one programming language. Divided into five groups, each group was assigned a smaller scope based on their research interests. By the end of this development stage, a lower-level scope definition was identified for each group, as shown in Fig. 1, with the exception of the visualizer, which was added and developed at a later stage.

As shown in Fig. 1, the federation consists of six federates that interact during the run time to reflect the operation behavior: 1) controller; 2) loader, which is responsible for loading and dumping trucks and also calculates the production rate and equipment utilization; 3) mover, which handles trucks' movement on the road; 4) breakdown module, which is responsible for equipment breakdown and maintenance; 5) weather, which generates weather parameters (e.g. snow depth, wind speed, and precipitation) according to project location and start date; and 6) visualizer. The factors affecting the earthmoving operation are categorized and represented in separate federates. This approach provides better exploration of those factors, as each factor can be modelled in more depth and accuracy.

Federation object model

Following each cycle of scope definition and investigation of available mathematical models for simulation behaviors, each development team identified their simulation object model (SOM). This model is a collection of object classes and their attributes that the team would either need to receive their values from other federates, or would provide values for them during simulation execution. Once SOM's are individually identified, teams collaborated on merging them into a federation object model (FOM), which represented the union of these SOMs. A subset of the FOM for the earthmoving simulator is illustrated in Table 1. The table also shows the interests of each federate in the FOM. The classes and attributes corresponding to the interest of one federate either in publishing (P) or subscribing (S) represent the SOM for that federate. For example, the SOM for the breakdown federate includes Equipment-Location, Equipment-Model, and Equipment-BreakdownState. The latest version of the FOM for the simulator included six object and interaction classes and thirty two attributes that are shared between the different federates.

Table 1: Sample of the federation object model FOM (P = publish, S = subscribe, PS = publish and subscribe)

Attribute / Parameter	Type	Controller	Weather	Mover	Loader	Breakdown	Visualizer
Object Class							
Equipment							
Location	Point3D	S		PS	S	S	S
Model	String	PS		S	S	S	S
BreakdownState	Enum	S		S	S	P	S
Capacity	Float	P		S	S		
Interaction Class							
CurrentWeather							
Temperature	Float	S	P	S	S	S	S
WindSpeed	Float						
Visibility	Float						
SnowFall	Float						
Precipitation	Float						

EXAMPLE 1: CONTROLLER FEDERATE

As the name implies, the controller federate controls the simulation execution using the HLA services to create the federation. A conceptual structure of the controller module is shown in Fig. 2. It contains two separated parts: the federate and the interface. Separating them as two components smoothed the development process and gave the opportunity to replace the interface easily without affecting the core federate.

The simulation starts when the controller federate sends a call to the RTI stating its intention to create the operation federation. The creation, as shown in Fig. 3, is done through a user-friendly interface that enables users to enter their operation attributes for simulation-based evaluation. The interface enables the user to connect to a local host or IP address, and it shows a list of joined federates. The federate implements the "IWriter" interface, which will ensure that the interface has a logger window to receive updates from the controller federate. The interface subscribes to controller federate events to receive updates (for example controller federate fires an updateTruckStatus event when it receives a new truck status from the RTI), while functions are used to send requests (e.g. advance in time) to the RTI through the controller federate. Using events from the controller federate in the interface enables using different interfaces without crashing the controller federate, and it gives the flexibility of using multiple interfaces at once, if required.

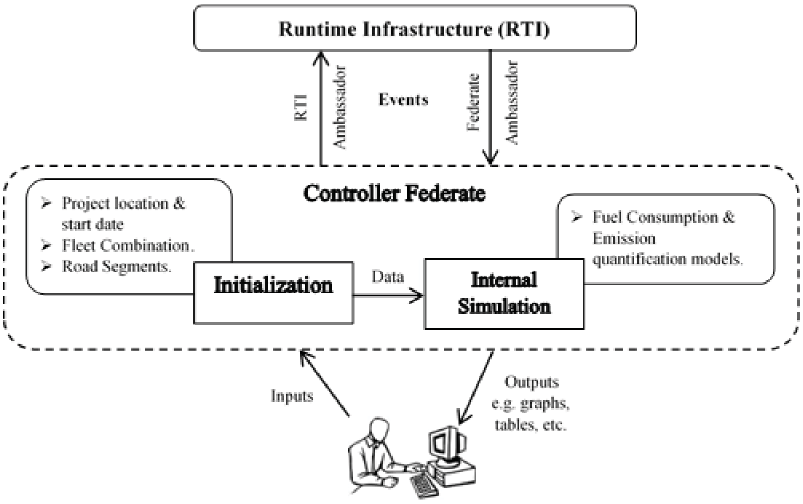


Fig. 2: Controller federate structure

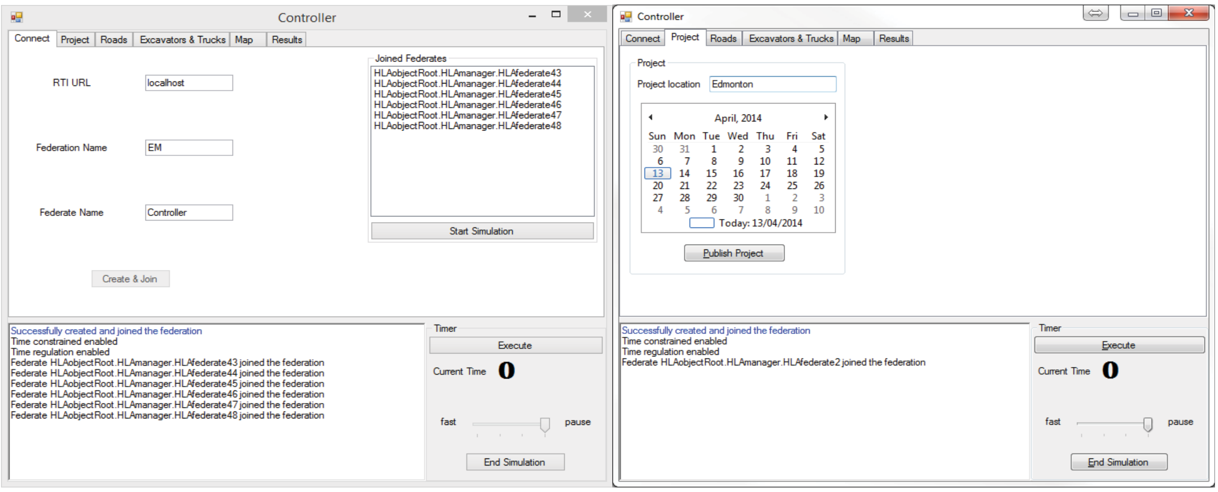


Fig. 3: Simulation set up (federation creation and project attributes)

The controller federate has an SOM that describes the federate characteristics, and focuses on the details of its internal simulation without concerning the RTI. Table 2 shows a sample of the controller federate SOM. It can be noted that the controller is only subscribing to the attributes needed to perform its simulation and publishing attributes needed by other federates.

Receiving confirmation for the existence of the federation execution allows the controller federate, as well as other federates, to join and resign in any sequence. Once all federates are joined, the controller federate starts the simulation allowing internal simulation activities to start. In order to synchronize internal simulation of each federate, a number of synchronization points are used for the transition during the execution: “ReadyToDeclare,” “ReadyToPopulate,” “ReadyToExecute” and “ReadyToTerminate.” The RTI keeps track of each federate synchronization point separately; however, transition will only be achieved when all joined federates reach the same synchronization point.

Once all federates achieve the “ReadyToDeclare” synchronization point, each federate declares its intention to the RTI to publish or subscribe to certain attributes that are needed by the federate to internally start its simulation. The state of the instance is used by federates as the primary means of communication. Federates could acquire the ownership of the object instance attribute that allows the federate to update the values of that attribute. Subscribing to the object instance attribute is always accompanied by object instance discovery, which enables the federate to receive notifications from the RTI when a new instance has been created. The RTI sends notifications to all federates subscribed to the object instance attribute when the owner federate updates its values through the HLA reflect service.

The operation requires a number of object instance attributes to be initialized to start the simulation. Once all federates achieve the “ReadyToPopulate” synchronization point, the controller federate defines the scenario to be experimented by defining the project location and the start date (Fig. 3), and populating the number of instances for each object class and some of the initial attribute values. The controller federate also initializes the combination of the fleet, their models, capacity and the empty weight of the trucks using the “Excavators and Trucks” tab, as shown in Fig. 4. The federate defines the road section that will be used for the hauling and returning operation and all the attributes of the road segment. It can define multiple roads and segments with different attributes, such as different segments’ material.

The road sections can be read from DXF® files; however, the user can modify the coordinates before publishing (Fig. 4). Road segments represent a list of lines defined by their end point coordinates, while road section is a list of road segment IDs. Fig. 5 demonstrates an example of road sections and segments. There are six road segments shown in the table and two road sections (Road 1 contains road segments 1, 2, and 3 and Road 2 contains road segments 4, 5, and 3). One road segment can be used in multiple roads.

Table 2: Sample of the simulation object model (SOM)

Attribute / Parameter	Type	Semantics	Controller
Object classes			
Equipment			
Model	String	CAT 797B, Teren Titain, Liebherr	PS
Capacity	Float	maximum capacity in metric tons	P
Truck			
MovingState	Enum	values: Hauling, Returning, Stationary	S
RollingResistance	Float	Value in %	S
CycleTime	Float	Truck cycle time	S
TKPHLimit	Float	Tire parameter specified by the user (TKPH)	P
TireTKPHAchieved	Int64	Quantity of times truck achieved TKPH	S
Excavator			
UtilityRate	Float	Utility Rate of Excavator, in %	S
RoadSegment			
Id	Integer	road segment id	P
Node1	Point3D	end point of road segment	P
Node2	Point3D	end point of road segment	P
Material	String	Stone, Slag, Dolerite; Default: Stone	P

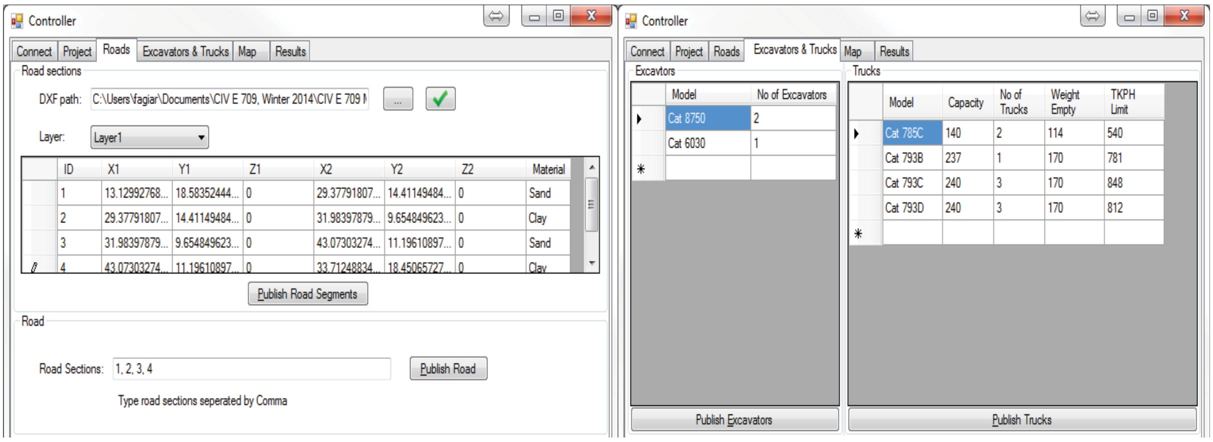


Fig. 4: Road and fleet characteristics

ID	X1	Y1	Z1	X2	Y2	Z2
1	0	0	0	5	0	0
2	5	0	0	5	5	0
3	5	5	0	8	5	0
4	10	0	0	10	5	0
5	10	5	0	5	5	0
6	7	8	0	9	9	0

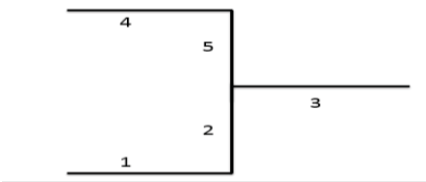


Fig. 5: Road segments and sections

Other federates receive notifications about the created instances and the updated instances’ values. By achieving the “ReadyToExecute” synchronization point, the controller federate starts the execution of the simulation that allows other federates to start their internal simulation and publish their results. Then, the controller starts its own simulation when receiving updated values for the subscribed object instances attribute values from others to quantify some of the operation performance indicators—namely, trucks’ fuel consumption, and their Carbon

Monoxide (CO) and Nitrogen Oxide (NO_x) emissions based on known quantifying model. The model adopted was proposed by Joseph and Szymanski (2013), and it quantifies the fuel usage for trucks based on 12-hour shifts, as shown in Equation 1-1. Their model quantifies the other emissions, as shown in Equations 1-2 and 1-3.

$$\text{Fuel Usage } (\text{l}/12\text{hrs. ton}) = 160\ \text{RR\%} + 545 \qquad \text{Eq. } 1 - 1$$

$$\text{CO } (\text{g}/\text{hr}) = 122 * (\text{TR\%}) - 2 \qquad \text{Eq. } 1$$

$$\text{NO}_\text{x} \text{ or HC } (\text{g}/\text{hr}) = 27.5\ (\text{TR\%}) - 3 \qquad \text{Eq. } 1$$

Where, RR = rolling resistance
GR = grade resistance
TR = total grade resistance = RR + GR

The controller internally quantifies the grade resistance for each road segment, and as it subscribes to the rolling resistance published by the Mover federate, it receives those values for each truck created and stores them in a class. All the values will be used to quantify the fuel and emissions for each truck and those values are published every minute. The federate instantaneously receives other federates' results that represent the sequence of events and changes in some of the operation performance indicators and displays them in an animated fashion. The visualization section articulates, in detail, the representation of all results. Once all federates achieve the "ReadyToTerminate" synchronization point and declare their intention to resign from the federation execution, the controller federate ends the simulation and destroys the federation.

EXAMPLE 2: VISUALIZATION FEDERATE

After completing the first release of the federation, a visualizer federate has been added to the federation in order to provide a user-friendly visual medium for observing some of the dynamic behaviors of the federation in a 3D virtual world. To build this visual world, 3D assets are collected from different sources. For instance, an input comes from an AutoCAD® file, which contains the topography of the operation area. The topography file is converted to a ".3ds" file through Sketch Up® as in Fig. 6 (at the moment, this is done manually; however, future work aims to automate the process or feed the AutoCAD file directly into the visualizer). The visualizer federate displays a 3D animation model for the operation. The model has been built on WPF® 3D library, which provides a fundamental 3D class and Helix 3D Toolkit®, which enhances the WPF library by providing pan, zoom and orbiting operations. The Helix 3D Toolkit supports reading .3ds files, which have been used to load the topography into the model.

Once it has joined the federation, the visualizer federate loads and displays the topography of the area (mine, roads, and dumping site). When the controller publishes excavators and trucks to the federation, they will immediately be displayed in the visualizer. For this operation, three truck models have been created: CAT 797B, Teren Titain, and Liebherr. Those models were built in Sketch Up® and then exported in .3ds format; however, any other truck model can be easily added by creating its .3ds file.

In the initialization stage, the trucks start empty on the dumping site. As the simulation's time advances, the Mover federate publishes each truck location based on its speed, which is used by Visualizer to animate trucks' movement on the road. Once the truck reaches the mine, the Loader federate takes its ownership from the mover federate to be loaded, and afterward, returns the ownership to the Mover federate again to return the truck to the dumping site. The loading state is visually represented on the model.

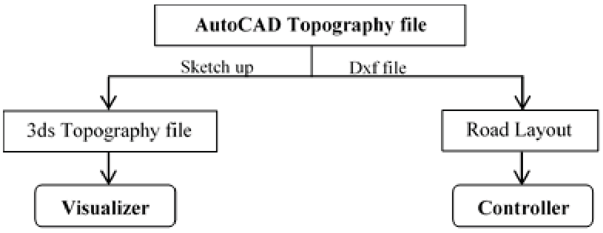


Fig. 6: Operation area topography is read by visualizer and controller from AutoCAD file

If a truck is flagged as broken by the break down federate, it will stop moving and will be shown with a red light on top, as shown in Fig. 7. If the user hovers the mouse over any truck, a textbox will appear that shows the truck's data, such as model, capacity, and cycle time. The user can also navigate the model using the pointing device (pan by clicking on the scroll wheel, zoom by scrolling, and rotate the model using right click). The user can control the animation speed through the controller. This enables users to navigate and better understand the operation.

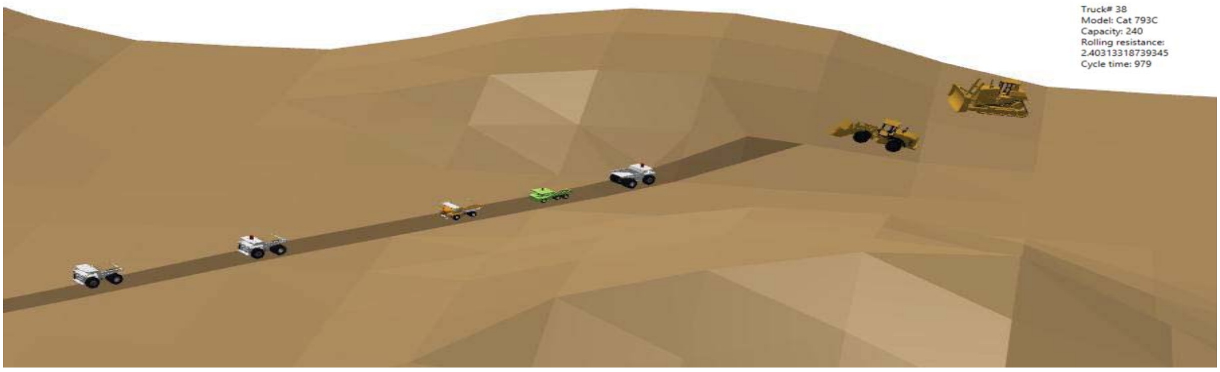


Fig. 7: The visualizer model

As the simulation advances in time, the controller federate displays the simulation key statistical outputs (e.g. production rate, truck break down percentage) in a graphical and numeric fashion. Truck break down is shown in Fig. 8-A, which displays the breakdown events vs. time, while Fig. 8-B displays the breakdown percentage. Those results are published by the breakdown federate; it applies probability distributions defined by the user to express breakdowns and maintenance, and it considers crews' availability and weather parameters.

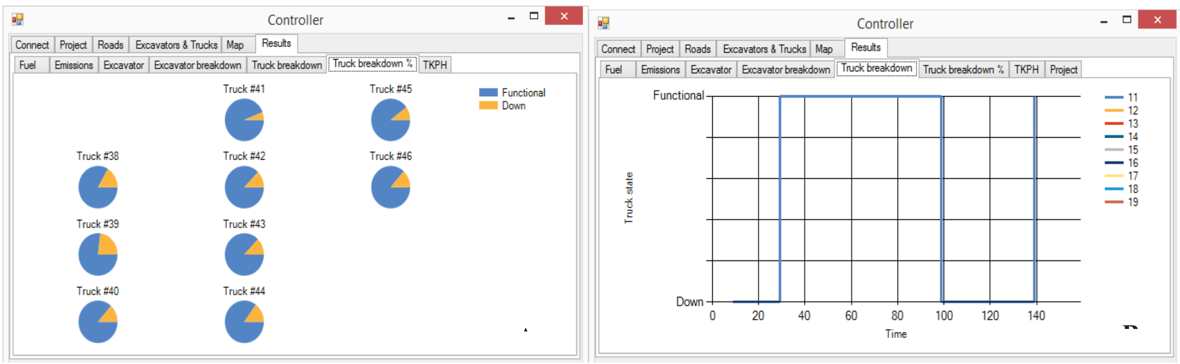


Fig. 8: Trucks' breakdown

Fig. 9 shows trucks' fuel consumption and the project emissions quantified by the controller federate. Trucks are presented in different colors in Fig. 9-A, and the trucks' emissions are accumulated to quantify the whole project emission, and are presented in a different color in Fig. 9-B. A tabular format is used to display project and excavators' production rates and trucks' cycle time, quantified by the Loader and Mover federates, respectively, as shown in Fig. 10-A. As the user defines the limit for tires' Tons kilometers Per Hour (TKPH), Fig. 10-B displays the TKPH for each truck; exceeding the specified limit will result in truck breakdown.

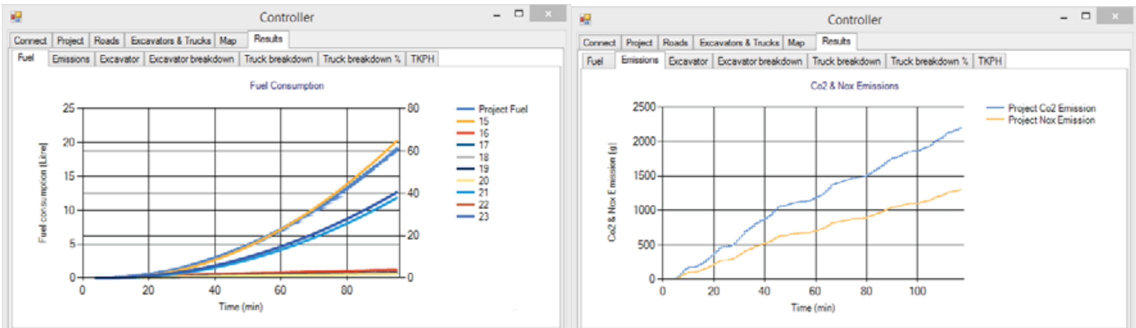
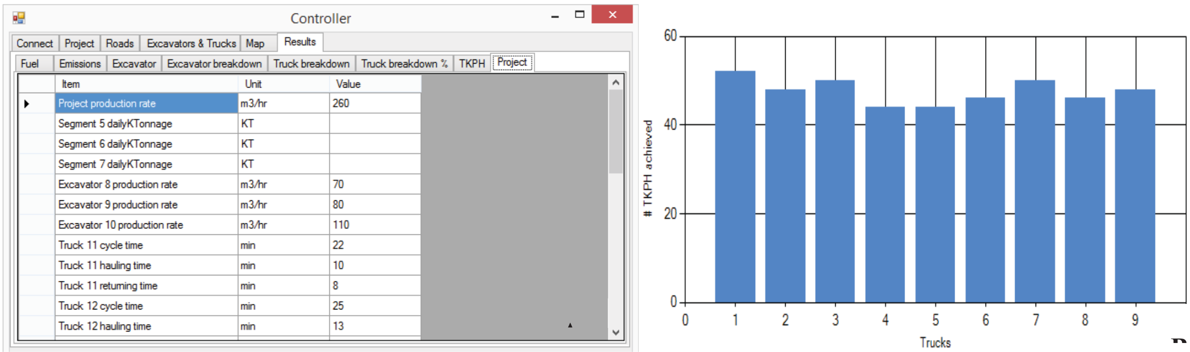


Fig. 9: Trucks fuel consumption and project emissions



Item	Unit	Value
Project production rate	m3/hr	260
Segment 5 dailyKTonnage	KT	
Segment 6 dailyKTonnage	KT	
Segment 7 dailyKTonnage	KT	
Excavator 8 production rate	m3/hr	70
Excavator 9 production rate	m3/hr	80
Excavator 10 production rate	m3/hr	110
Truck 11 cycle time	min	22
Truck 11 hauling time	min	10
Truck 11 returning time	min	8
Truck 12 cycle time	min	25
Truck 12 hauling time	min	13

Fig. 10: Project and excavator production rates, trucks' cycle time and TKPH limit achieved

CONCLUSION

In this research, distributed simulation approach has been used to model the factors affecting earthmoving operations with a wider scope than previous studies. This paper demonstrates the process followed for developing a comprehensive simulator through collaboration of different developers using HLA standards. Two components of the simulator were also presented as examples. The first one is a controller component with a user-friendly interface that allows decision makers to investigate their desired scenarios. The interface enables its users to observe the simulation outcome instantly in a graphical and statistical fashion as the simulation advances in time. The second is a 3D visualization component that was later added to the simulator, which enables visualizing trucks' movement and functionality for better tracing and understanding of the simulated behaviors of the operation.

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RESOURCE PLANNING IN PANELIZED CONSTRUCTION BASED ON DISCRETE-EVENT SIMULATION[1]

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ABSTRACT: *Construction industry is moving towards off-site construction method for better quality, improved productivity and control. Panelized construction is one of the most adopted off-site construction system where panels are built in factory environment and then transported to the construction site for on-site erection by using crane. As a primary emphasis in the production line management of panelized construction, resource allocation inside the production system plays a significant role in the productivity improvement. This paper thus explores a discrete-event simulation-based approach to conduct construction resource planning in the production plant with the objective of improving productivity and balancing the production line. More specifically, the number of resource employed in the production factory is simulated and optimized by means of discrete-event simulation. To achieve the objective, Simphony.NET, a simulation engine developed at University of Alberta, has been applied to develop the simulation model which mimics the production process and to perform "What-if" analysis in terms of different resource allocation strategies. The simulation results show that proper resource allocation improves the production performance and simulation is a useful planning tool for the construction industry.*

KEYWORDS: *Discrete-event Simulation; Panelized construction; Resource allocation, Production Line Management*

❖ INTRODUCTION

For decades, the construction industry has suffered a lot from the no-growth productivity and construction waste problems, in comparison with a significant productivity improvement and less waste experienced by the manufacture industry. In the meanwhile, construction practitioners are also trying to introduce the manufacture technology to the building industry, and to produce the buildings in the factory environment in order to improve the current practice. In this context, panelized construction is being increasingly adopted in the building industry as a primary construction method where panels are built in factory environment and then transported to the construction site for on-site erection by using crane. This method transfers on-site construction activities into production tasks in a factory, and also switches the construction management into the production line management. As a primary concern of construction practitioners, resource allocation among the production system plays a significant role in the productivity improvement, and is also daily basis work for production managers. Traditionally, construction resources are allocated based on practitioners' experience and intuition without the support of scientific technology. In fact, the computer simulation technology provides an essential tool for the manager to experiment with and evaluate different scenarios. Based on the simulation results for different scenarios, decision making is straightforward in relation to the production performance so as to produce building product in an economical and efficient way. On the contrary, the decision based on time-cost tradeoff analysis without computer simulation tools for different postulated scenarios is extremely challenging.

Discrete-event simulation (DES), one of the computer simulation technologies, enables practitioners to mimic construction process and investigate resource allocation strategies prior to the project execution and has been of interest to the scholars in the construction industry. Some research has been conducted to study the DES methodology and to develop some typical DES engines, such as CYCLONE (Martinez et al. 1999), STROBOSCOPE (Martinez et al. 1996), Simphony (AbouRizk et al. 2000) and SDESA (Lu 2003) in order to customize DES for construction projects. In the meanwhile, DES is also being gradually utilized in construction industry to assist construction practitioners in project planning and productivity improvement in practical projects. Some typical examples include work done by AbouRizk and Dozzi (1993), Lu (2008), Liu et al. (2012), and Altaf et al. (2014). More specifically, AbouRizk and Dozzi (1993) applied CYCLONE to solve dispute resolution problem in bridge jacking operations. Lu et al. (2008) extended SDESA to perform resource-constrained critical path analysis by means of integrating DES with particle swarm optimization. Liu et al (2012) utilized DES to examine different mobile falsework utilization methods in bridge construction. Later, Altaf et al. (2014) integrated Simphony with particle swarm algorithm to optimize the wall panel production sequence.

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This study employed discrete event simulation to perform "What-if" analysis in terms of resource allocation in the production line system which is designed to produce wall panels for family houses. A wall production line system at Landmark's prefabrication plant in Edmonton was presented as a case study. Firstly, a simulation model in *Simphony* was developed to mimic construction operation processes in this paper. Then, the simulation model was validated by comparing actual time data collected from the Radio-frequency identification (RFID) system installed at Landmark prefabrication plant site data with simulation results. Further, different scenarios pertaining to resource allocations were simulated and compared to study the effect of different resource allocations on the performance of the production line system. This paper is aiming to use discrete event simulation to examine different resource allocation strategies and their impact on the production makespan, to identify the bottleneck of the production line and finally to assist the construction practitioners in improving the productivity of the production line system with the maximization of resource utilization.

OVERVIEW OF PANELIZED CONSTRUCTION PROCESS

Panelized home production includes three main production lines – (1) Wall production; (2) Floor production; and (3) Roof production. This research mainly focuses on the wall production line as this is more complex than floor and roof production process. Figure 1 shows the wall production line at Landmark's prefabrication plant in Edmonton. There are various kind of production line assembly and the panel production line can be considered as a mixed-model asynchronous assembly line where *n* number of panels go through *m* number of stations in a series configuration (Xie et al. 2011).

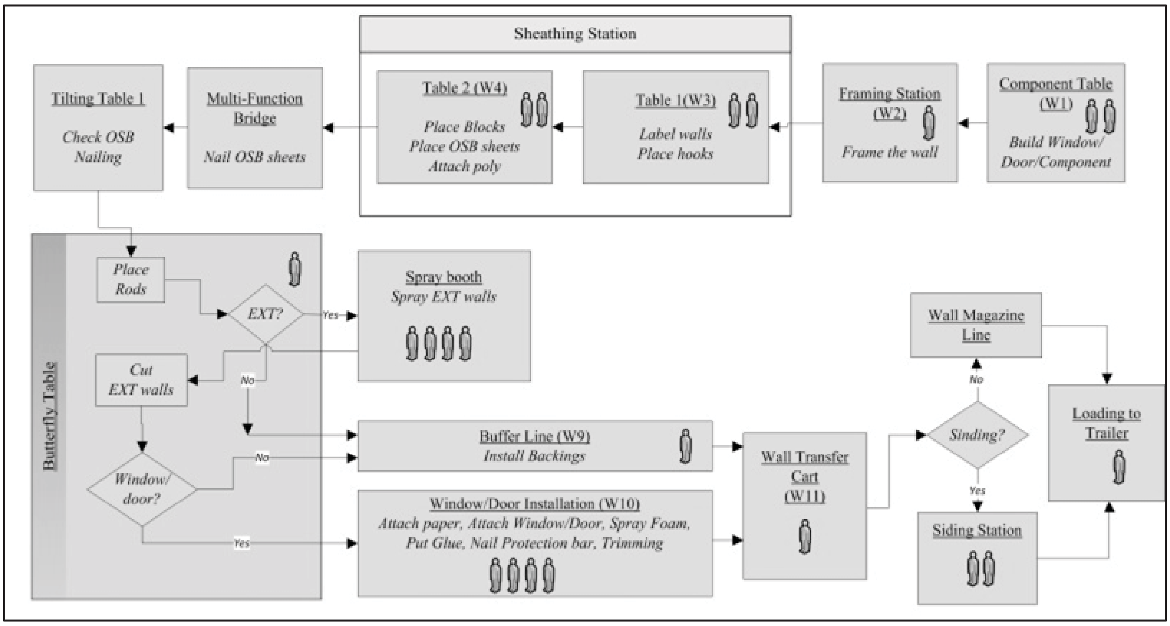


Fig. 3: Wall production line at Landmark prefabrication plant

The wall production line starts at the component table where windows, doors and other small components are built and feed to the framing station. At framing station, the wall panel is built using a CNC machine that reads the panel 3D model from computer and nails all the studs and other components to the top and bottom plate of the panel. One worker only feeds all the studs to the automatic nail guns. The maximum capacity of all the stations in the production line is 40 ft. To utilize the full capacity of the table, multiple wall panels are built together in the framing station to make the total length close to 40 ft. The multi-wall panels are then transferred sheathing station where the panels are labeled, small blockings are nailed and OSB sheathings are placed for exterior wall panels. This sheathing station is consisted of two tables to allow buffer for the framing station. From sheathing station, the wall is transferred to the multi-function bridge where OSB sheathings are nailed by another CNC machine. From the multi-function bridge, then exterior panels are sent to spray-booth by a movable tilting table (butterfly table) in order to spray insulation foam. After that exterior multi-wall panels are cut into single wall panel. If the exterior wall has window/door, it will be transferred to the window installation station; otherwise it will go to the buffer line. Interior wall panels are moved directly to the buffer line where backing is installed if needed. From the buffer line and window installation station, single exterior wall and interior multi-wall panels are transferred to the wall magazine line using a transfer cart. Interior wall panels are shipped to the site as multi-wall panel in order to reduce crane lift on site which accelerates both the loading and unloading process. If the exterior panel requires siding, it will be transferred to the siding station directly from the window installation line. From the wall magazine line and siding station, the wall panels are loaded to the trailer using a loading cart and overhead crane.

SIMULATION MODEL

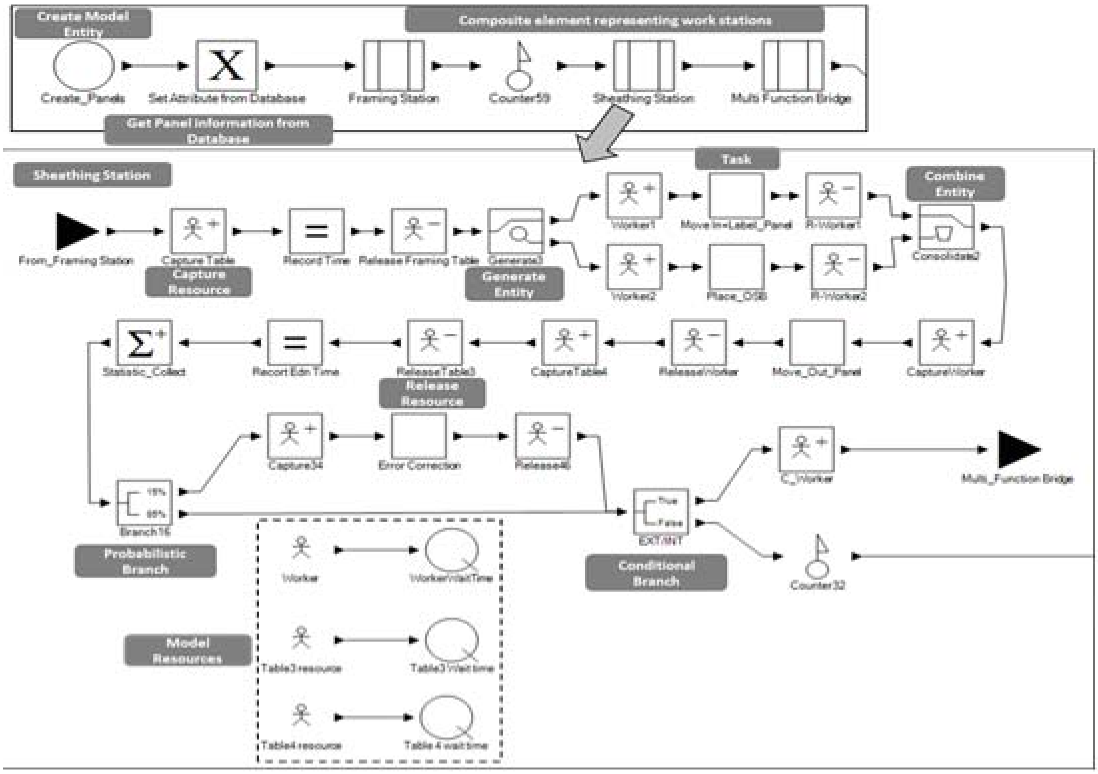
Simulation model of the Landmark's wall production line has been developed using Simphony.NET, a simulation engine developed at University of Alberta (AbouRizk and Mohamed 2000) to simulate construction activities. The simulation software allows the user to mimic the construction process by using different modeling element such as *create*, *task*, *set attribute*, *counter*, *branch*, *composite*, *execute*, *destroy*. The modeling environment provides the option to add different resources to the model and capture the resource before executing the task. In the production line model, multi-wall panel is created as the model *entity* using the *create* element, station and worker are created as *resource*, *task* elements are used to mimic the task associated with each station. *Branch* element is used to separate exterior and interior panel. After creating the entity, an *execute* element is used to connect the simulation model to the database to collect all the panel information. Each panel has different *panel-attribute* such as name, height, width, number of door/window/sheets of sheathing/stud/wall and so on. This information is stored in a database, reading from the 3D model of the wall panel. Inside the simulation model, each entity reads the database to assign these panel-attributes to the model entity.
A *task time formula* is written inside the *task* element in order to calculate the task time using the panel-attribute. The process time at each work station is considered deterministic by splitting the entire task into small task groups. By modeling in such way the probabilistic variation can be ignored and may be considered as almost deterministic (Halpin and Riggs 1992). All the tasks that take place at the sheathing station and associated panel-attribute with the task are presented in Table 1. The time associated with each task is calculated from time study conducted at Landmark's prefabrication plant. Each task time will be calculated by multiplying the quantity of the associated panel-attribute and the time. For example, if a wall panel has 10 sheets of sheathing, the time needed to place all the sheathings will be 10×0.30=3 min. In the simulation model, panel processing time is calculated from two parts –a deterministic part – the task time formula, and a stochastic part representing delay/error correction which follows a triangular distribution.

Table 1: Task associated in Sheathing Station

Task	Time (min)	Panel-Attribute
Receive Panel	0.50	n/a
Take Out Bracings	1.00	No. of Component
Place Interior Door Header	1.00	No. of Interior door
Drill holes & install nuts and pins	0.50	No. of Drill holes
Label walls	0.85	No. of Walls
Attach poly on the top of the walls (2nd floor walls)	1.00	n/a
Install blocking (Exterior walls)	1.00	No. of Blocking
Place sheets of sheathing (Exterior walls)	0.30	No. of OSB
Nail sheets of sheathing (Exterior walls)	0.32	No. of OSB
Move the panel to the next station	0.50	n/a
Error correction (Probability of Occurrence 15%)	2.00	n/a

Figure 2 shows the detail model of the sheathing station with all primary modeling elements in Simphony.NET. The *entity* enters the sheathing station by capturing the *sheathing table3* resource and releasing *framing station* resource following the capture. Then the simulation time is recorded using *set attribute* element. The entity generates one more entity from the *generate* element in order to execute multiple task simultaneously. The model is designed in a way that each *entity* is required to capture a *worker resource* to execute each *task* and release the *worker resource* after finishing the task. After completing both task separately, two entities merged together using consolidate element. If one task is completed earlier, it will wait until the other entity completes the task. The entity can only move forward once both tasks are finished.

After completing all the tasks at *table3* the entity again capture one *worker* to transfer the panel to the next table. If the following table is occupied, the *entity* will wait inside the *waiting file* element associated to that resource. Once the following table becomes available, the *entity* will capture the resource and execute the task by capturing the *worker*. Similar to the table resource, at any time, if the *worker* resource is not available, the *entity* will wait inside the *waiting file* element. A *probabilistic branch* is used to simulate the delay due to error correction. 15% of time, the *entity* will go the error correction task in order to mimic the delay. A *conditional branch* is used to separate exterior and interior panel by reading the panel attributes. The entity exits the sheathing station once the following table resource becomes available.



This modeling technique enables the user to perform "what if" analysis by changing the number of *worker* at different stations for the purpose of different resource allocation strategies. The simulation model will generate results such as recourse utilization, waiting time at each station, station processing time, and total time to produce all the panels (makespan).

RESULTS AND DISCUSSION

Simulation Model Validation

The simulation model is validated based on actual time data collected from the Radio-frequency identification (RFID) system installed at Landmark prefabrication plant. Currently, the RFID system has been installed as a pilot program at the framing station and sheathing station to collect actual production data. The simulation result has been compared with these two station's actual time data to validate the task time formula. Figure 3 shows the comparison of actual and simulation data for framing and sheathing station. The x-axis represents the actual process start time of each panel at the station and y-axis represents the total production time in minutes. Landmark produces exterior and interior wall separately in day and night shift as the work load is different. The simulation model is run for exterior and interior walls separately with the actual production sequence and also considered the break time. For both type of wall, the simulation results matched with the actual production time at framing and sheathing station.

Resource Planning

Simulation based resource allocation strategy has been used in Landmark's prefabrication plant. The analysis is performed separately for exterior and interior wall to get the optimum number of workers in different stations. The optimization criteria are to minimize throughput time and maximize station and worker utilization. Simulation model is used to find an optimum number of workers which will balance these two objectives. As framing station, butterfly table, and transfer cart requires only one worker, the resource modifications are made for sheathing station and window installation station. Table 2 shows the simulation result for different number of worker at sheathing and window installation station for exterior wall panel production. The utilization of station and worker is calculated based on the following equation.

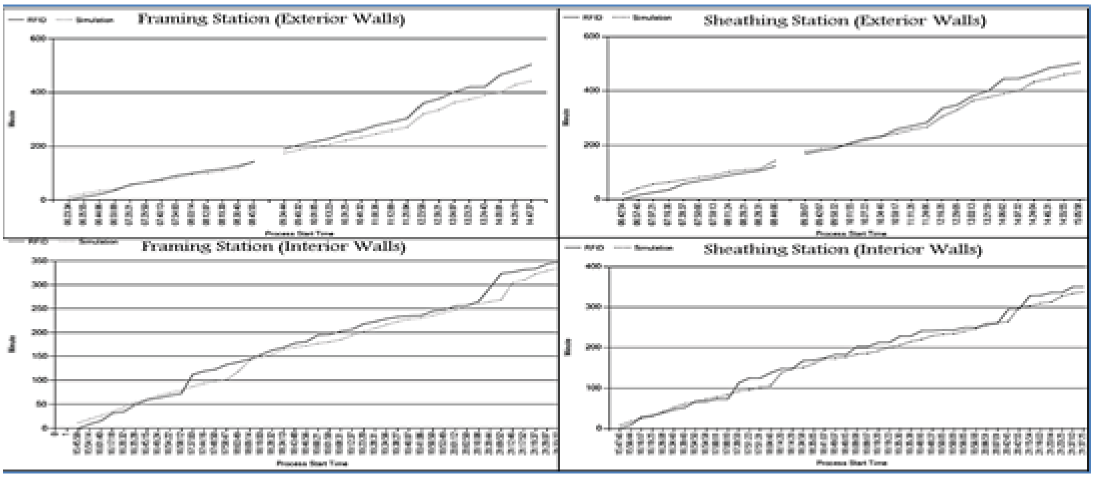


Fig. 3: Cumulative production time comparison (Actual vs Simulation)

$$Utilization = (Total\ Work\ Time) \,/\, (Total\ Work\ Time + Idle\ Time) \qquad (1)$$

Total work time and idle time is calculated from the simulation model for both resources. The result shows that the optimum number of worker at sheathing station can be 3-5; while the optimum number of worker at window installation station is 4-5. Assigning more workers reduces the panel throughput time but also decrease the utilization of worker. To identify the value of adding extra worker to a station, the total makespan need to be considered. Table 3 summarizes the makespan time for different number of worker at sheathing and window installation station for 31 exterior wall panel productions. The result shows that adding more than 4 workers at sheathing and window installation station add little value to the overall production. With 4 workers at each station the mean makespan is 669 min while adding one extra worker at window installation station will reduce the total production time by only 4 minutes. Increasing more workers at both stations eventually has no effect as the downstream station (loading of panel) controls the makespan.

Table 2: Resource utilization for exterior wall production

Station	No. of worker	Throughput (min)	Worker Utilization (%)	Station Utilization (%)
Sheathing Station	2	37	95.32	72.61
	3	29	76.14	65.61
	4	25	61.58	58.71
	5	25	49.3	59.48
	6	21	42.49	49.39
Window Installation Station	3	103	88.97	-
	4	64	77.39	-
	5	51	65.76	-
	6	49	57.54	-
	7	48	47.95	-

Table 3: Effect of different number of worker on the makespan for exterior wall production

Number of worker at sheathing station	Number of worker at window installation station	Makespan (min)
2	3	822
2	4	778
3	3	768
3	4	685
3	5	688
4	4	669
4	5	665
5	4	664
5	5	659
4	6	660

Figure 4 shows the worker utilization chart for 4 workers at both sheathing and window installation station. The utilization chart shows that the workers at sheathing station stay idle at the end portion of production as sheathing station is located at the beginning of the production line. Similarly, the window installation workers are idle at the beginning and also at the end as it is located in the middle of the production line. The simulation considers the entire simulation time to calculate the resource utilization which will not give the actual utilization of the worker. The simulation result has been corrected by deducting the idle time at the beginning and end of the production in order to calculate the actual utilization of worker.

Similar resource planning has been conducted for interior wall production. For the interior wall, there is no window installation work, only backings are installed at the buffer line. Table 4 shows the utilization and makespan for different number of worker to produce 44 interior walls. The number of worker at sheathing station and buffer line is changed to see the effect on the makespan. The simulation result shows that the optimal combination is 2 workers at sheathing station and 1 worker at buffer line. As the utilization of buffer line worker is low with 32.15%, an alternation option has been tested where 3 workers are assigned for both stations. This increases the worker utilization to 98%, however, the total production time also increases by 12%

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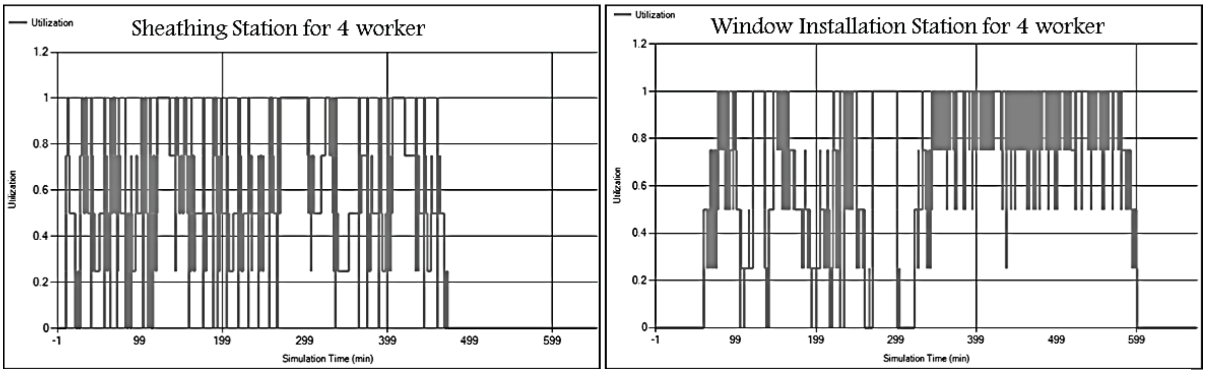

Fig. 5: Worker utilization chart

Table 4: Effect of different number of worker on utilization and makespan for interior wall production

No. of Worker at sheathing station	Sheathing worker Utilization (%)	No. of worker at buffer line	Buffer line worker Utilization (%)	Makespan (min)
3	48.28	1	34.64	460
2	63.68	1	32.15	463
1	98.44	1	28.80	481
3	98.62	0	-	518

CONCLUSION

This paper has successfully applied Simphony.NET to develop production line model and to evaluate resource allocation strategies for different wall panel types. In order to develop the simulation model, time study for each station has been conducted, and task duration has been further formulated as equations and used as inputs of the simulation model and the equation has been validated using actual time data. Different combinations of workers at sheathing and window installation station have been simulated in order to find the optimal number of worker. The result shows that simulation model can provide valuable insights about the resource utilization and its effect on total production time. The production controller can assign workers based on the production need. Adding extra worker does not always increase the productivity by any significant amount to justify the additional cost associated with the extra worker. In future work, worker salary can be integrated with the simulation model in order to provide a cost comparison for different resource allocation options.
Successful implementation of the simulation based resource analysis in Landmark's wall production line also illustrates the value of using simulation based planning and control system in panelized production. The use of simulation model can be extended to production scheduling, performance evaluation, production control, and balancing the production line.

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UPGRADING THE AUTOMATED CRANE MANAGEMENT SYSTEM FOR INDUSTRIAL CONSTRUCTION PROJECTS[1]

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ABSTRACT: *The abundant oil sands reserves in Alberta, Canada enrich Alberta's economy, and catalyze the construction of large-scale heavy industrial projects. For these industrial projects, an off-site modular construction approach is frequently utilized in order to achieve more effective and efficient installations. In this approach, large portions of the project are broken down into modules that are prefabricated off-site and shipped to the site for installation with mobile cranes. Considering the frequent use of mobile cranes and the heavy weight of the lifted objects, detailed and careful lift plans must be prepared prior to actual lifting. These lift plans must consider many factors, such as lifting capacity, clearance checking, and ground bearing pressure (GBP). In addition, the large number of lifted modules makes the lift plan process more tedious, and any minor change in scope may result in a complete reworking of the lift plan. Therefore, the following research provides a novel solution to managing heavy lifts more efficiently by automatically checking the lifting capacity, clearances, and lift path planning for thousands of lift options. The developed system is based on a server database where all the required information is housed. The designed lift plans are presented in terms of a lift study, as well as a time-dependant lift animation. A case study based on a real project is elaborated upon to validate and deomonstrate the efficiency of the proposed system.*

KEYWORDS: *industrial project; mobile crane; lift study; 3D animation; modular; capacity checking; clearance checking*

❖ INTRODUCTION

In Alberta, Canada, heavy industrial projects are constructed using a modular approach.
Module components, such as pipe spools and steel, are prefabricated in the factory and assembled together at module yards. The entire module is then shipped to the site by truck, and installed on site by mobile cranes; (Fig. 1 shows the construction chain for industrial projects). The modular construction chain frequently involves engineering design and analysis. From a contractor's perspective, one of the most critical steps in terms of engineering design and analysis is to guarantee a safe and efficient on-site lifting process. The lifting process heavily relies on large mobile cranes with expensive fees for rental and mobilization. An accurate and reasonable plan for the lifting process means high productivity; on the other hand, poor design can easily delay the lifting and increase project costs, as well as increase the likelihood of safety risks due to inappropriate lifting. To ensure the accuracy of the lift plan (also known as the *lift study or rigging study*), engineers need to perform a variety of calculations. For instance, the lifting capacity check, which determines if the mobile crane has sufficient lifting capacity based on the capacity charts provided by the crane manufacturer, must by accurately derived. Considering the large quantity of lift (for a typical industrial project, the number of lifted modules can easily exceed 100) and the complexity of lift plans, the manual-based rigging study process is not sufficient for day-to-day project management requirements. Consequently, automated approaches are demanded for lift analysis.
Previously, many efforts have been made to develop systems and algorithms that can accelerate the process of crane analysis. This previous research can be generally categorized into the following: (*i*) selecting the appropriate crane type for the lifting jobs (Hanna and Lotfallah 1999; Wu *et al.* 2011; Hasan *et al.* 2013; Jacek *et al.* 2014); (*ii*)

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determining the optimal crane locations/supply locations (Huang *et al.* 2011; Safouhi *et al.* 2011; Lien and Cheng 2014); (*iii*) simulating and visualizing the lifting processes using computer technologies (Al-Hussein *et al.* 2006; Tantisevi and Akinci 2009; Lin *et al.* 2012; Lee *et al.* 2012; Juang *et al.* 2013); and (*iv*) studying the feasibility of crane lifting process using robotic motion planning method (Chang *et al.* 2012; Zhang and Hammad 2012; Lei *et al.* 2013a and 2013b). PCL Industrial Management Inc. has collaborated with the University of Alberta to develop a system that can improve the construction process for industrial projects. This collaborative work focuses on how to locate mobile cranes on industrial projects (Hermann *et al.* 2010 and 2011), considering the feasibility of lifts (Lei *et al.* 2013a and 2013b). Simulation is also a useful tool that has been adopted to solve module yard production problems (Taghaddos *et al.* 2014). Moreover, the research presented in this paper introduces an aspect of the heavy lift management system developed by PCL Industrial Management Inc. and the University of Alberta, which is currently being utilized on a daily basis in actual industrial projects. A case study is also elaborated on in order to demonstrate the efficiency of the system.

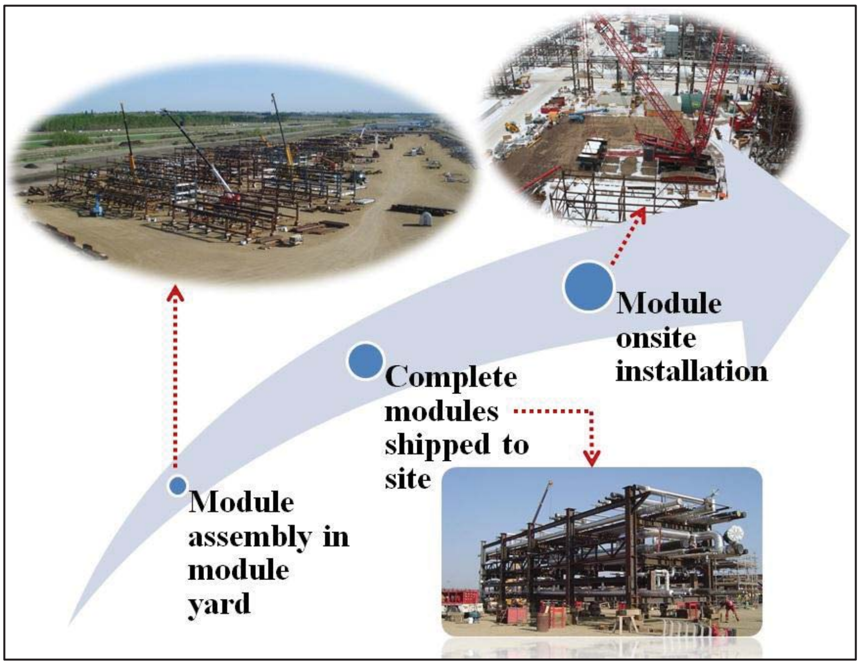


Fig. 1: Construction chain for a heavy industrial project

SYSTEM ARCHITECTURE

The developed heavy lift management system is data-driven, and built based on a central database where project and crane information is stored (see Fig. 2 for the system architecture). Information contained in the central database includes the following: (*i*) module dimensions, weight, and lifting dates; (*ii*) site boundaries; and (*iii*) crane configuration, lifting capacity chart, and hook block capacity. Currently, the database stores parameters for 300 mobile cranes with 26,000 corresponding crane configurations. There are a total of 394,000 crane capacity entries. The proposed database also interacts with several programs: (*i*) the Advanced Crane Planning and Optimization (ACPO) system, which aims to mathematically select and optimize the location of the mobile cranes based on lifting capacity and clearance requirements; (*ii*) the Advanced Simulation in Industrial Crane Operations (ASICO) system, which utilizes the lifting logic and populates the optimal lifting sequence; (*iii*) Crane Path Checking & Planning (CPCP), which checks the feasibility of the lifting process based on the results of ACPO and ASICO; (*iv*) *Heavy Lift Planning Toolbox*, a newly developed component which provides a user-friendly and efficient tool for practitioners to perform time-dependent lifting clearance checking; and (*v*) Navisworks® (general lifting animation) and 3ds Max® (detailed lifting animation), tools through which to animate the results. The focus of this paper is on introducing the *Heavy Lift Planning Toolbox*, including a discussion of how to use 3ds Max® to automatically animate the results.

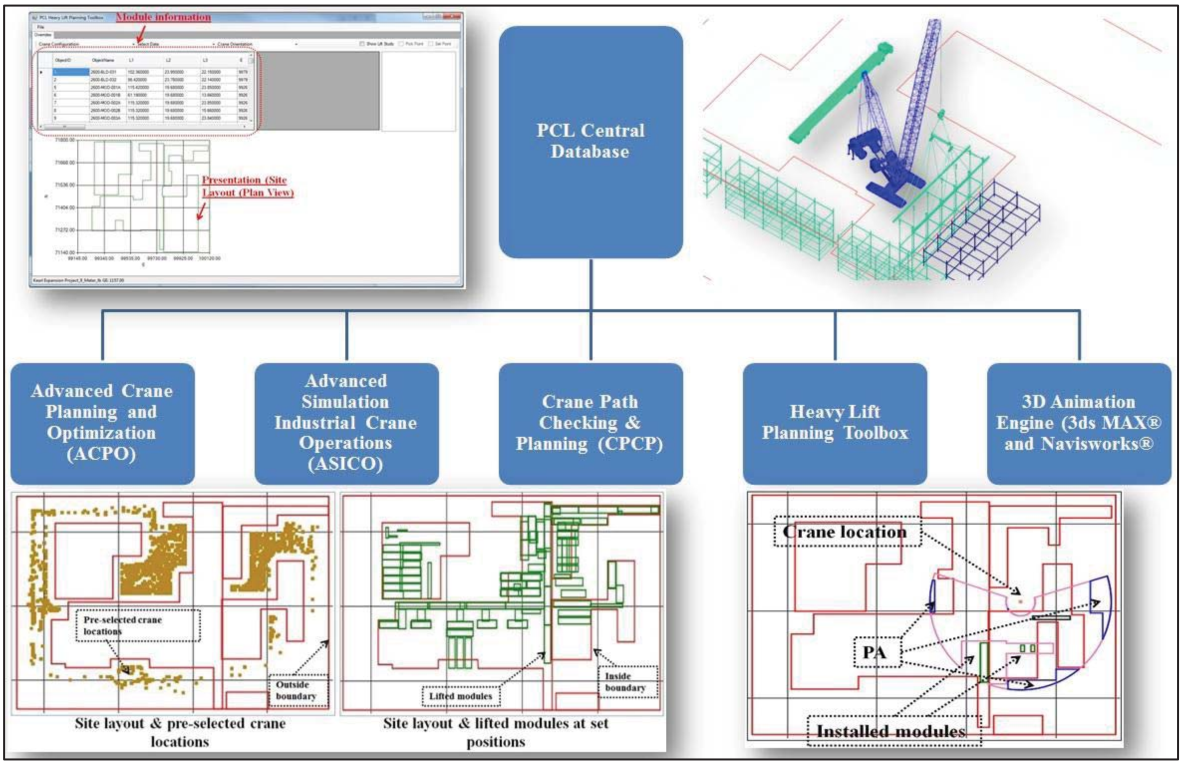


Fig. 2: System architecture of heavy lifting management system

TIME-DEPENDENT LIFTING CLEARANCE CHECKING

To avoid collisions between the mobile crane and lifted or stationary objects during lift operation, the boom and crane body clearance must be verified to ensure sufficient clearance for the crane at its pick and set position. Although verifying clearance may not seem complex and time-consuming, repeating the task for several hundred module lifts increases the workload substantially; in addition, minute site changes will force lift engineers to frequently reassess these clearances. The most common approach to clearance verification is to use AutoCAD® crane and module models to plot the lifting scenario and manually check the clearance. Engineers can also use mathematical approaches to calculate the clearances, such as the approach introduced in Shapiro (2011). This approach finds the point representing the shortest distance from the boom to the obstruction and, based on that point, calculates the clearance; however, the interpretation of the "closest" point varies depending on approach used. In this research, the *Clipping Algorithm* is used to check the boom clearance. As a result, all the possible points that can cause collisions are also determined. In terms of the calculations, the variable, time, is considered insignificant (less than a second for congested construction sites). Based on this method, the *Heavy Lift Planning Toolbox* is developed; through the use of which engineers can instantly check the clearances for mobile crane operations.

For calculation purposes, the mobile crane is represented by the numerical parameters shown in Fig. 3 and Fig. 4. The values of these parameters are retrieved from the manuals provided by the crane manufacturer; these parameters are then inputted and stored in the central database. Other relevant mobile crane information must also be entered into the database, such as: (*i*) the lifting capacity chart, which defines the safe working load (SWL) for the crane to lift at specific lifting radii; (*ii*) the hook block information, which consists of the SWL of the hook block, number of hoist lines, etc.; and (*iii*) the reeving capacity information, which defines the SWL for the different combinations of hoist lines. Rigging information is also taken into account, such as information pertaining to slings, shackles, spreader beams, and turnbuckles. In the database, each mobile crane configuration is distinguished by a unique configuration ID used to track the crane's parameters through the entire program. Once the crane parameters are defined, the *Clipping Algorithm* is used to calculate the boom clearances. The algorithm can be traced back to Vatti's polygon clipping method (Vatti 1992), which is a widely used concept in computer graphics by which to determine whether the portion of a given picture is within, overlapping, or outside of another region. A General Polygon Clipper (GPC) library has been developed by the University of Manchester that supports four types of clipping operations: *intersection*, *exclusive*, *union*, and *difference* of subject and clip polygons (see. The main process of using GPC to calculate the boom clearance of the mobile crane consists of two steps: (*i*) detecting the potential collision points for boom; and (*ii*) calculating the boom clearances based on the potential collision points.

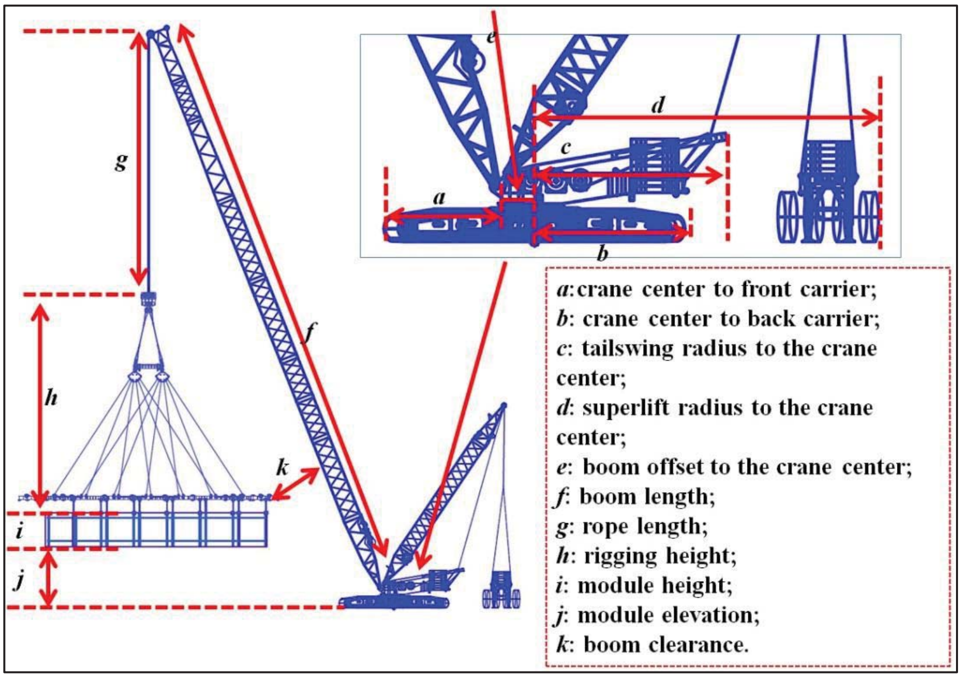


Fig. 3: Parametric representation of a crawler crane from an elevation view

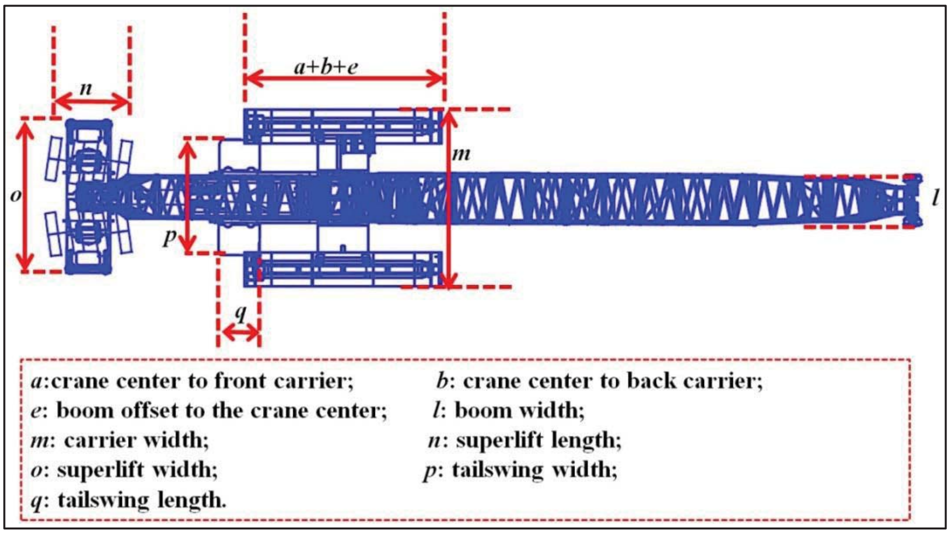


Fig. 4: Parametric representation of a crawler crane from a plan view

Given the general crane lifting case in Fig. 5, the boom clearance checking process is as follows:

(i) Create a virtual downward boom envelope BE^3 (Fig. 5).

(ii) Find the potential collision polygon ($P_{collision}$) using Eq. (1) (*Clipping algorithm*). The $P_{collision}$ represents a 2D polygon that may have a potential collision with the boom. The vertices of the defined polygon are the potential collision points (*PCPs*). Also, the *PCPs* can be anywhere on

the modules, the surrounding obstructions (SO_i), or the rigging.

(iii) Calculate the perpendicular distance (D_i) from each potential collision point to the boom.

(iv) Compare all the distances with the allowed boom clearances and all potential collision points that satisfy the boom clearance requirement. These distances are recorded in the safe point set, which is formulized as Eq. (2). Any instance in which a potential collision point does not satisfy the requirement indicates that the given crane lift has a collision.

$$P_{collision} = BE^3 \cap SO_i \quad (i = 0, 1, 2, ..., n) \tag{1}$$

$$P_{safe} = \{(x, y, z) | D_i \geq D_{buffer} \; and \; (x, y, z) \in PCP\} \tag{2}$$

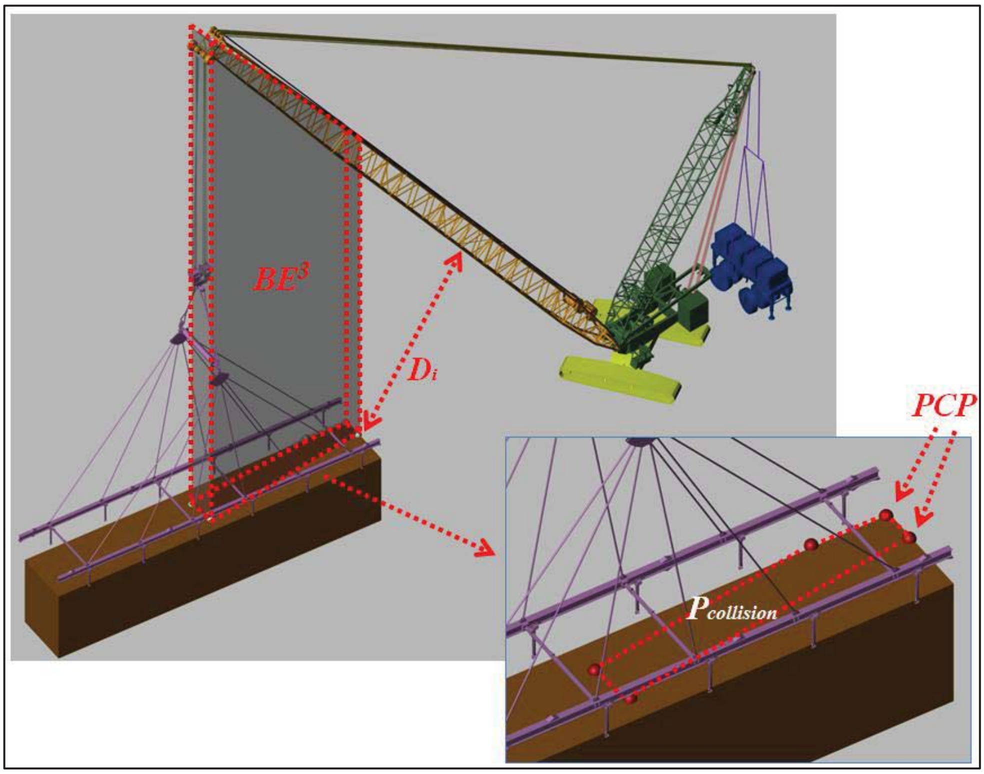


Fig. 5: Boom envelope and potential collision points in 3D space

3D VISUALIZATION OF MOBILE CRANE OPERATIONS

Once the selected crane locations pass the clearance checking, the lifting animation can be generated using 3ds Max®. Imported as an AutoCAD® model, a mobile crane in the 3ds Max® environment should have certain additional components in order to operate, such as *bones* and *dummies*. *Bones* are used to move the crane components (*e.g.,* boom up and down, and rotating the crane body), while *dummies* are used to track the locations of 3D objects (*e.g.,* tracking the location of the lifted module in the animation). Hierarchy is integral to the movement of mobile cranes, and *linking* is used to create this hierarchy. An example of hierarchy is shown in Fig. 6. The *crane body bone* controls the entire movement of the crane components, including *Superlift (tailswing) bone* and *boom bone*. However, the movement of the *boom bone* (the boom operation) does not affect the location/rotation of the crane body. Such hierarchies are programmed using MAXScript, (a language provided by 3ds Max® for software customization), in order to automatically add *bones* and *dummies*, as well as to conduct necessary *linking*. After the crane model is ready for animation, the following generic steps are followed to generate the crane animations: (*i*) lift up the module from its pick location; (*ii*) adjust the module to be perpendicular to the boom; (*iii*) rotate the module to the front of the crane and walk the crane to its set location (if it is a crane walking scenario); and (*iv*) align the boom to the set direction and place the module to its set location.

IMPLEMENTATION AND CASE STUDY

Heavy Lift Planning Toolbox

The *Heavy Lift Planning Toolbox* has been programmed using VB.NET language which connects with the central server database. The project information can be downloaded from a server. The module information is then stored temporarily in a *datagridview*, and an MSChart is used to show the site layout from a plan view. In Fig. 7, examples of modules (plan-view) are presented time-dependently. The left pane in the figure shows a module lifted on April 27, 2013 when the site is relatively spacious. On July 13, 2013, the site is quite congested since the project has progressed. Mobile cranes at both pick and set locations can be plotted according to the crane configuration assigned to each module. One example is given in Fig. 8, in which the weight of the lifted module is 277,832 lb (126,022.48kg). The Demag CC-2800 mobile crane with a Superlift attachment is used to lift the module, and the lift date is July 13, 2013. The site is plotted time-dependently, and the mobile crane is shown at its set location. An AutoCAD® model is used for comparison with the plotted symbolic model. In addition, the designed interface has a magnifying feature that allows the user to zoom in to view the details. It is calculated that the mobile crane uses 70.8% of its lifting capacity at the pick position and 65.5% at its set position. The capacity calculation considers the module weight, rigging and hook block weight, which together are used to search its lifting capacity in the crane capacity chart provided by the manufacturer. The clearance checking results using the *Clipping Algorithm* are shown in Fig. 9. The shortest distance from the boom to the obstructions is determined to be 25.16 ft (7.67m), which means this lift can be feasibly performed.

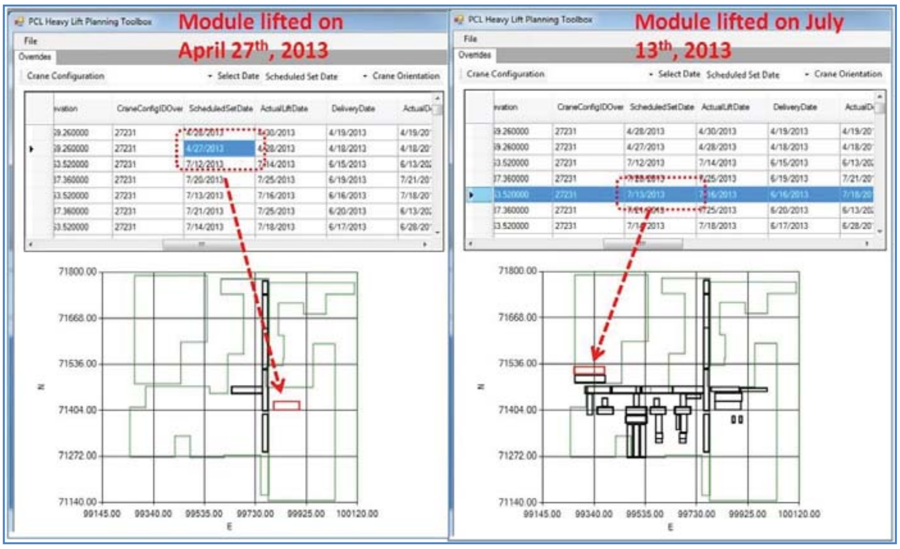


Fig. 7: Time-dependent on-site module lift examples

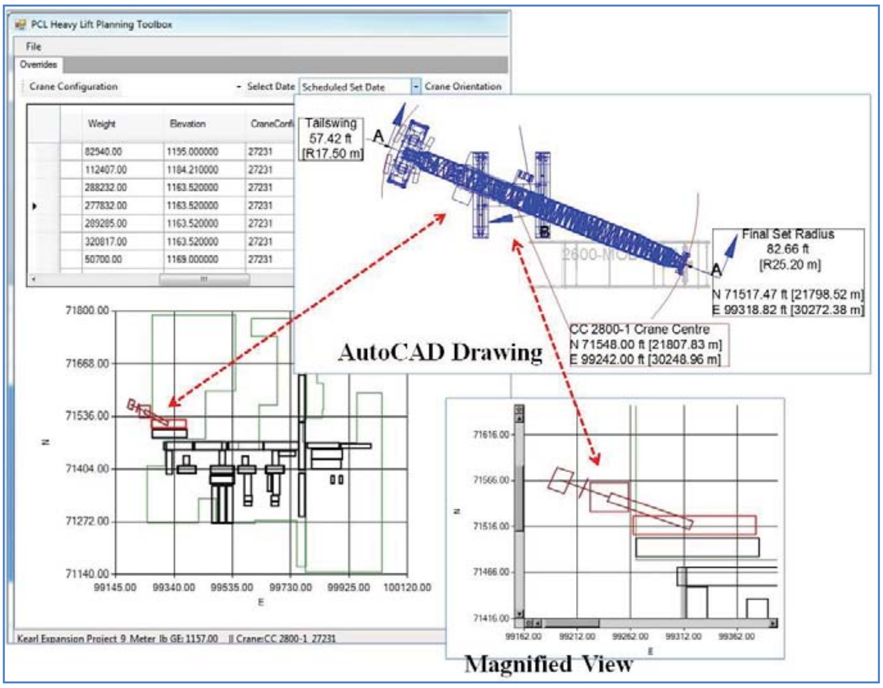


Fig. 8: Symbolic crane model for Demag CC-2800

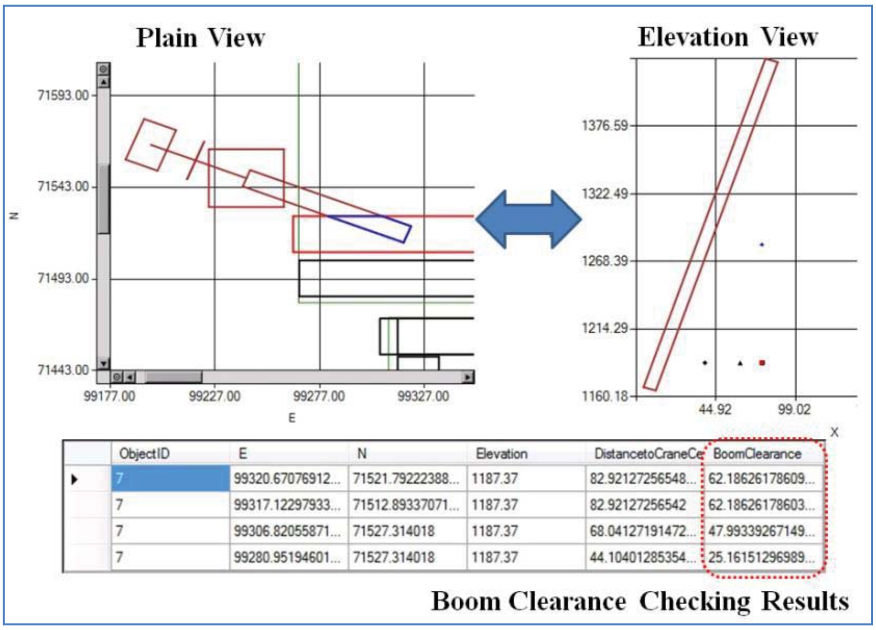


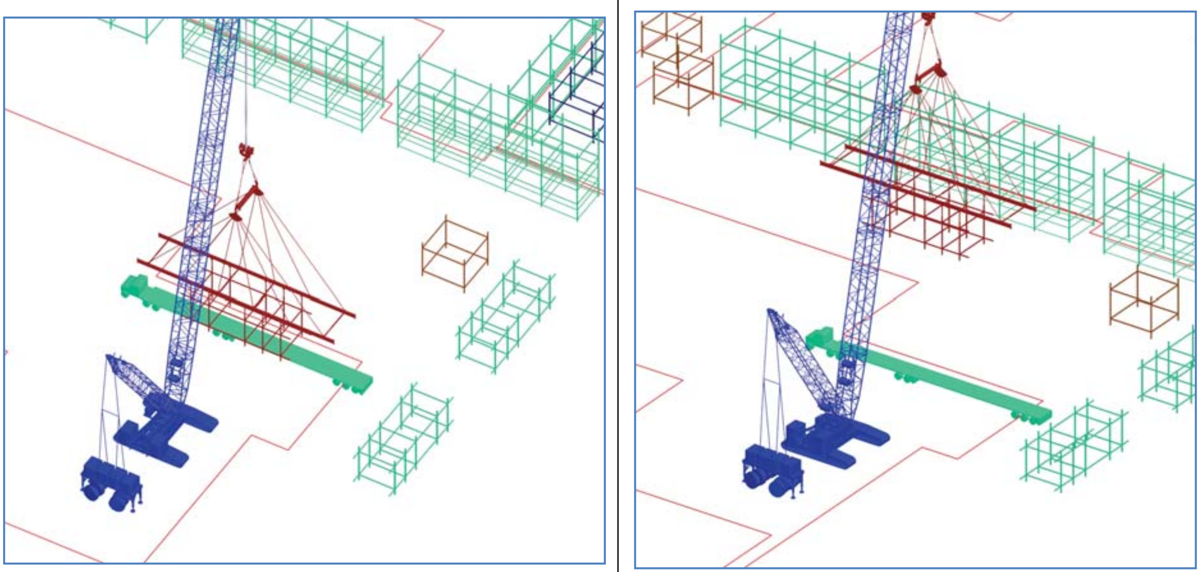
Fig. 9: Boom clearance checking results

3D Visualization of Crane Operation in 3ds Max®

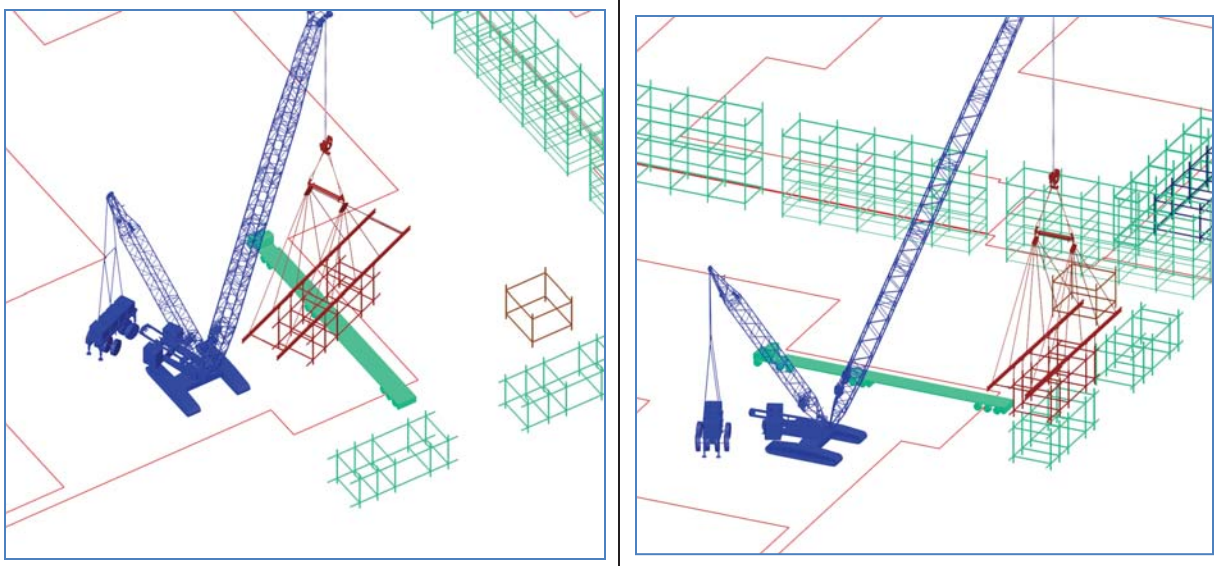
Once the selected crane locations pass the clearance checking, the lifting process can be automated in the 3ds Max® system. In general, the developed system can handle two types of crane operations: the pick-and-swing scenario, in which the mobile crane rests at one specific location and performs the lift without walking; and the crane walking scenario, in which the mobile crane must walk with the load in order to complete the lift in a congested area. The lifting process is programmed following a generic pattern in MAXScript, and the program can retrieve the needed crane and module locations from the central database. Necessary components such as *bones* and *dummies* are automatically created in order to operate the crane model. Fig. 10 shows the mobile crane lifting a piperack module. In the background, other modules are placed on-site prior to the target module's lift date.

CONCLUSIONS

This paper has described a system developed by the University of Alberta and PCL Industrial Management Inc. to efficiently manage mobile crane operations. The automated system shown in Fig. 2 can manage crane location selection, check the feasibility of lifts, and visualize the planned results for thousands of lift options. As one of the sub-systems, the *Heavy Lift Planning Toolbox* is an easy-to-use system for clearance checking. Based on a parametric concept, the mobile crane's geometry is represented by various parameters, and these parameters are used together to check the clearance using the *Clipping Algorithm*. The system is time-dependent, allowing engineers to test the lift in a "what-if" scenario. Eventually, the planned results are visualized in 3ds Max® by programming the lifting process using MAXScript. Currently, the designed system has proven efficient in actual industrial projects by reducing many-hour planning and visualization process to minutes. However, there exist limitations such as the motion speed of the mobile crane operation is not considered. In the future, the authors will explore the possibility of optimizing the crane lifting process and "virtually" operating the crane movement using a gaming engine to detect potential safety issues related to lifts.



(i) Module pick-up	*(ii)* Module lift-up



(iii) Module swinging	*(iv)* Module set-up

Fig. 10: Piperack module lifting animation

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CAN BIM SUPPORT BETTER WORKING CONDITIONS FOR LOW-SKILLED LABOUR?[1]

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ABSTRACT: *A potential surplus of 95 million low-skilled workers and a shortage of similar amount for high skilled workers are expected around the globe by 2020. The construction sector provides employment which is a must need for many of the poverty-stricken and most vulnerable people. It provides opportunities, inter alia, to low-skilled as well as entry-level workers seeking work in the construction sector. In addition, the construction industry plays an important role in providing work to rural-to-urban migrants who travel just for earning by doing. The construction world is full of challenges to the main stakeholders. Owners as well as contractors face global and local market issues, wherein all construction projects must meet local authority approvals. Construction projects often run for several years, and one big problem for the construction contractors is to hold construction labor for continuous work according to the planned schedule. However, workers sometimes appear only during seasonal breaks (i.e. farmers), the duration of which is only few months. The challenge for sustainable construction processes is to hold and educate the available low-skilled workers in a short time in order to qualify them for the individual construction tasks, which are necessary to be performed on the running projects.*
The research project currently underway at the Bauhaus-Universität Weimar is designed to look for the employability of low-skilled workforce of the construction industry by the application of Building Information Modeling (BIM) technology. The BIM modeling allows for detailed descriptions of the typical one-of-a-kind construction processes within the environment of the individual construction project. The research in the longer run aims to maximize productivity and efficiency as well as providing ease and quality in work performance of low-skilled labor force through BIM simulation and communication technology. This aspect of research has vital impact on performance of construction projects due to diversity in location and employed work force. BIM application in this regard is still an unexplored research area. A kick-off to the project has been made for workability of educating and training low-skilled labors with BIM environment through visualization. A three-dimensional (3D) BIM Model of a parking garage has been made to highlight the possible aspects of using BIM design and visualizing tools in lieu of educating the low-skilled construction manpower.

KEYWORDS: *Building Information Modeling, Construction, Low Skilled Workers, Construction quality*

❖ INTRODUCTION

The construction industry is of strategic importance not only to the developed but the developing economies as well. There is no doubt that the developing countries have experienced a major increase both in the output and the employment in the construction sector in the last four to five decades. The construction is always treated as a major investment component; hence expansion in construction activity is closely related to economic growth (Wells, J., 2001). Besides the provision of growth to other industries through backward and forward linkages, the construction industry generates substantial employment opportunities worldwide (Khan, 2008). With more than 7 % employment to the workforce of Europe, the construction sector ranks first among the employers in the continent (Proverbs D.G., et al, 1999). In addition, the construction sector in the United States of America accounts for some 14 % of gross national product and around 8 % of total employment (Thieblot A.J., 2002).
Construction has the ability to "absorb the excluded" (de Souza, 2000). By fulfilling the social responsibility, the construction sector provides employment to the world's poorest and most vulnerable people. It also provides opportunities to low-skilled or entry-level workers and to those migrating from the countryside. Besides developing countries, the construction sector also provides much needed employment in the developed world to

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[1] Citation: Bargstädt, H. J., Nasir, A. R. & Ignatova, E. (2014). Can BIM support better working conditions for low-skilled labour? In: N. Dawood and S.Alkass (Eds.), Proceedings of the 14th International Conference on Construction Applications of Virtual Reality, 16-18 November 2014, Sharjah, UAE.

those with few academic qualifications (Wells, J., 2001). It provides opportunities to long term unemployed force as well as those out of labor force (Dougherty, 1996). With the cost per job created in construction being lower than any other sector of the economy, construction is seen as an “employment-spinning” sector (Vaid, 1997).

Gone are the days when construction provides employment only for local rural-urban migrants. In case of the developed world, the industry also attracts and absorbs migrants from other countries with labor surplus and lower wages when the pool of migrant workers from the rural areas dries up (Wells, J., 2001). By a report in 2012, McGraw-Hill Construction had forecasted that in addition to residential construction, non residential construction including building sectors like commercial, institutional and industrial will grow up to 1.73 times over the levels of 2011. The real estate market in Russia, developing quite rapidly with the planned volume input of up to 70 million sq. meters per annum. In 2012, the number of people employed in the Russian construction industry amounted to almost 7 million and the current employment trend will result in some serious implications in regard to the availability of skilled workers. For the ‘Power of Siberia’, a pipeline construction project between Russia and China, approximately 11,700 skilled workers have been engaged in 2014 (Unity, 2014).

The skilled labor shortage is not a new issue for the industry. Its effects have been felt for decades. Despite the tremendous growth which the construction industry had, it is still wrestling with significant workforce challenges (Whyte & Greene, n.d). Actually it is not only construction; every industry which depends on skilled craft workers is feeling its shortage (McConnel, 2007). The Institute of Management and Administration (“IOMA”) does not define the skilled craft shortage as a shortage of worker. Rather it defines the scenario as “a shortage of adequately trained, skilled, and productive workers available for certain jobs”.

In construction world, owners as well as contractors also face global and local market issues, wherein all construction projects must meet local authority approvals. At times, they typically rely on local labor resources to perform onsite activities with low or no skills of performing specific construction tasks which might affect the productivity and quality objectives. Although construction projects often run for several years, workers sometimes appear only during seasonal breaks. For example farmers leave their country only for some months between harvest periods.

Many construction projects integrate global resources (Eastman, 2008). As a result of this, multiple languages spoken on local project sites is also a common phenomenon these days which might create difficulty in instructing certain tasks to low skilled labors in the desired manner.

Therefore, an in time research is needed in order to look for accommodating such low-skilled workforce. BIM application, in this regard, is still an unexplored research area specifically for resolving human resource management issues. Therefore, this paper aims to look for workability of low-skilled workforce in construction industry with the innovation of Building Information Modeling (BIM) technology.

SKILL SHORTAGE AND TRAINING NEEDS

With an expected potential shortage of about 45 million high-skilled workers or 13 percent of extra-demand of such workers around the globe by 2020, McKinsey Global Institute’s report of 2012 also predicts a possible surplus of low-skilled workers. According to it, a potential surplus of about 95 million low-skilled workers (2.6 % of global workforce), or around 10 percent of the over-supply of such workers is expected by the end of this current decade. The break-up of such shortage of high-skilled and surplus of low-skilled workers in regard to developed and developing economies is presented in Figure 1. With these future scenarios in hand, some serious imbalances could be envisaged for the near future. If it happens, surely a long-term and permanent joblessness will be witnessed by every industry, where the construction sector will also not be an exception.

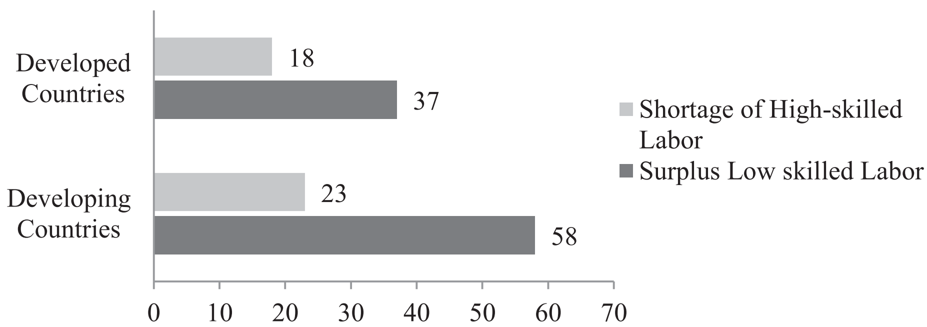

Fig. 1: Labor forecast up to 2020 in Millions (MGI, 2012)

Where the construction industry is requiring some highly skilled workers to perform certainly some complicated tasks, it is recruitment and replacement of such workers which is proving to be difficult. Lack of training, aging workforce and the construction industry's poor image to attract the youth are the additional reasons for such shortages (Olsen, et al, 2012). Aging workforce also came out to be the most prominent reason for a forecast ba Russian foreign ministry anticipating a shortage of 7 million workers by 2030. Today, the vacant seats are often occupied either by migrants or old people (Unity, 2014). Construction Users Roundtable (CURT), founded and driven by many of the largest and most successful construction owners in the United States, conducted a study in 2011, according to which 82 % of the survey respondents claimed experiencing skilled labor shortages on their projects out of which 78 % of respondents reported worsening of that shortage in the last three years (CURT, 2011). Construction Labor Research Council which maintains one of the largest and most reliable union wage, fringe benefits and contract terms databases in the construction industry in the United States, came up with the study that some 185,000 new workers need to be attracted each year upto 2015 with continuous training and retention policies so that the construction industry's expected turnover and growth expectations could be met (CLRC, 2005). Another research has shortlisted the demand of new skilled craft workers to be 200,000 to 250,000 each year (CURT, 2004).

On the other hand, construction has always welcomed those with few skill and low education levels. For instance, situations like the existence of construction projects at locations with high unemployment ratio make it a must for construction stakeholders to indulge the local people (low-/unskilled) as labor workforce on construction projects. In situations of acute skill shortage among workforce, it is required to train those surplus low-skilled workers at the earliest so as to meet the industry's demand. Skills are acquired by some labors in quick amount of time while in certain cases they take years to learn the desired skills. Construction workers usually learn the skills through combination of formal class-room instructions and on-the-job trainings (Wang, 2008). With a provision of construction craft training, worker aging problems could be resolved by attracting young workers in the construction industry (Liska and Weldzius, 2000). With an increasing demand of skilled workers in the times of their shortage, a considerable increase in on-the-job education is needed among others for desired improvement in the availability of skilled workers.

When it comes to educating the labor force, language barriers come in front with numbers of languages being spoken on a single construction site. These language barriers usually exist between project manager or the labor supervisor and the migrant workers and even among workers themselves. Problems such as lack of understanding and misunderstanding of instructions may arise owing to language differences (English, 2002). Breakdown in communication is thus caused among workers which results in bigger problems such as conflicts and low productivity (Ling et al, 2013).

Therefore, the challenge for sustainable construction processes is to educate the available low-skilled workers in a short time within probable language barriers in order to qualify them for the individual construction tasks, which are necessary to be performed on the current projects.

BUILDING INFORMATION MODELING

Building Information Modeling, commonly known through its abbreviation as BIM is defined by National Institute of Building Sciences (NIBS) as "a digital representation of physical and functional characteristics of a facility and it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward" (NIBS, 2007).

For sure BIM has been a major reason for increasing project quality, accurate schedules, extracting quantity take-offs and thereby total project costs as envisaged by Eastman in 2008. BIM has the ability to simulate the construction project in a virtual environment. With BIM technology, an accurate virtual model of a construction facility, commonly known as Building Information Model is constructed in a digital form. When completed, this information model contains precise geometry and relevant data required in support of design, procurement, fabrication, and construction activities required to realize the building (Eastman, 2008). This results in an intelligent and object oriented model with capabilities of parametric digital representation of the building, from which drawings and appropriate data can easily be extracted and then-after analyzed for in time decision-making and to improve the project delivery process.

BIM represents real world elements such as walls, doors, and windows as three-dimensional objects. In addition to geometric details, other information can be attached to these objects including manufacturers, fire rating, schedule, and cost estimates. By adopting this, the scope of work can be easily expressed and defined. Systems, assemblies and sequences can be easily shown in a relative scale within the entire facility or a group of facility (Azhar, 2011). Another BIM advantage is the interoperability function which provides ease to insert, extract, update, or modify digital data by owners, clients, engineers, architects, contractors, suppliers, and building officials (Goedert, 2008). An important thing to discuss is that BIM should not be treated as software, but rather as a process along with software. BIM has brought a large number of applications to various fields of AEC (Architecture, Engineering and Construction) industry, few of which may be visualization, design and constructability reviews, 4D scheduling and sequencing, 5D costing and estimation, prefabrication, structural analysis, energy and lighting analysis, conflicts and clash detections and facility management. Typical applications of BIM at different stages of a project are illustrated in Figure 2.

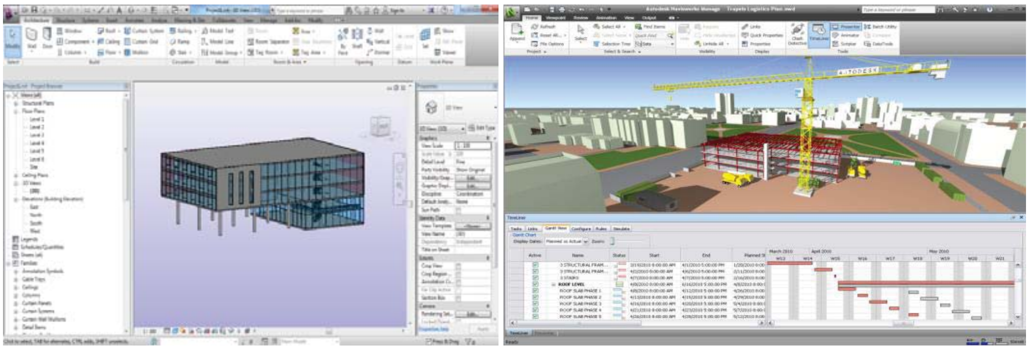

Fig. 2: Visualization during design and Construction Sequencing

As researched by Ignatova in 2011, studies associated with BIM technologies can be divided into three areas.

i. The analysis of the conditions of BIM implementation. In this direction, training BIM technologies, relationship between profitability of the use of BIM technologies with large scale projects and company profile are discussed. Moreover, the issues of quality, time, design work compared to other technologies are examined and the schemes of the organization of the collective team work are tested.

ii. The classification and definition of selection criteria for BIM applications. The functionality of the software, rational selection of the main software modules and programs of satellites are defined in this area. The standards and technical means, the organization coordinated work of BIM applications are chosen.

iii. The definition of priority directions of development of BIM technologies. This is the biggest area of research which can be attributed to the development of standards for data transmission, application integration, and intelligence software.

Undoubtedly a lot of research has been conducted for enhancing capabilities of BIM in design and construction, despite BIM being a recent development. However, a very limited research has been done so far on the impact of BIM on sustainable practices in construction which among others also includes its application to educate those workers working on construction sites with low skills and education. Convincing to say that these are the workers with whom the managers and supervisors also face problems due to communication barriers.

According to Eastman (2008) language barriers can also be overcome through BIM based simulation and communication. Most construction projects, either domestically or abroad, involve personnel who speak multiple languages or dialects in the office and field. Endeavors for having translation tools into CAD or even BIM fall short due to specific information commonly notated on drawings. As envisages by Sawyer (2006), BIM can be used to communicate daily field activities to foreign field workers. This interactive way will provide workers to navigate and query project information.

Projects often continue over long periods and involve numerous service providers. Project teams must continue to educate new project participants during each phase of the project. The computable nature of the building information models makes them an excellent tool for quickly bringing new team members up to speed, so they can understand the scope, requirements, and status of a project. This communication is vital, particularly when project ramps up or new participants join the team.

BIM FOR THE PURPOSE

For the purpose of floating the idea of education through BIM, a sample BIM model of a parking garage was developed. The idea is to look for the possibilities as to how to use the model for achieving the objectives of elaborating the end product by the supervisors to those laborers that are not educated up to a minimum required level, and who face communication barriers on site.

The model comprises of a gross area of 3180 sq. metres with a total parking capacity of 48 cars in two floors; each floor having a capacity to park 24 vehicles. Standard individual parking space of 2.64 m x 5.49 m with a parking

angle of 90 degree has been adopted in the model by following the standards provided by the Autodesk Revit. Entry and exit ramps to and from the first floor have been provided for vehicle movement. The garage has one entry and one exit point each for the vehicles. Figure 3 shows the Floor Plan and the 3D view of the parking garage model built in Autodesk Revit.
Aspects of teaching and educating low-skilled labors could get maturity through the very first common application of BIM i.e. visualization, which is the starting point for research on the subject theme. Those not so educated people could easily understand the end-product by viewing the 3D BIM model of a facility.

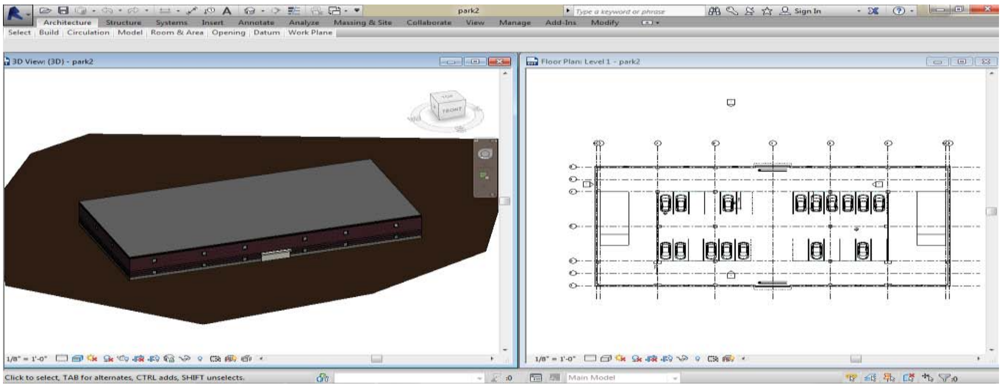

Fig. 3: 3D view and floor plan of parking garage

Viewing the model through various views could answer their unasked questions and make them realize what their employer would be demanding from their side. This reduces a possibility that a labor could leave the site in the starting period due to unawareness of their actual task for the unknown end-product.

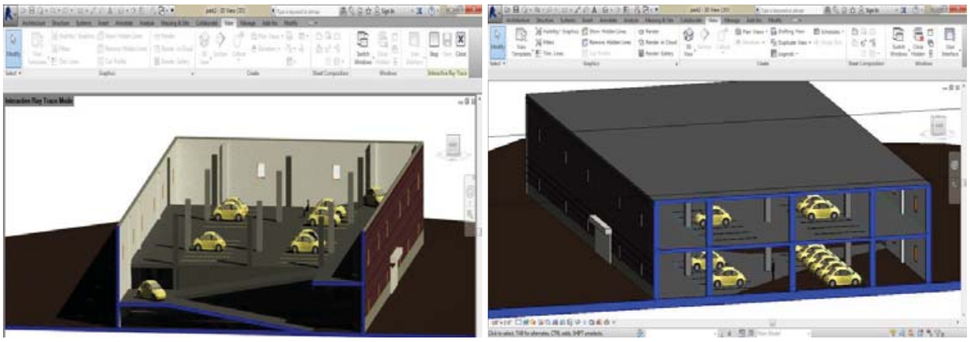

Fig. 4: Sectional views at project's different phases

Thus, this visualization will not only facilitate the designers and the managers, but also the work performing labor in different ways. Sectional views as shown in Figure 4 can be used for various phases of the project in order to let the workers visualize their tasks with the help of BIM Modeling.
Another BIM representation is also used in order to look for the details in the inside of the facility. The ramps to and from the first floor as shown in Figure 5, enabling the vehicles to park and proceed to the exit area, could be illustrated to the labor. The aspects of safety could also be informative as how those ramps will be provided with safety barriers during and after the construction for easy and safe operation.

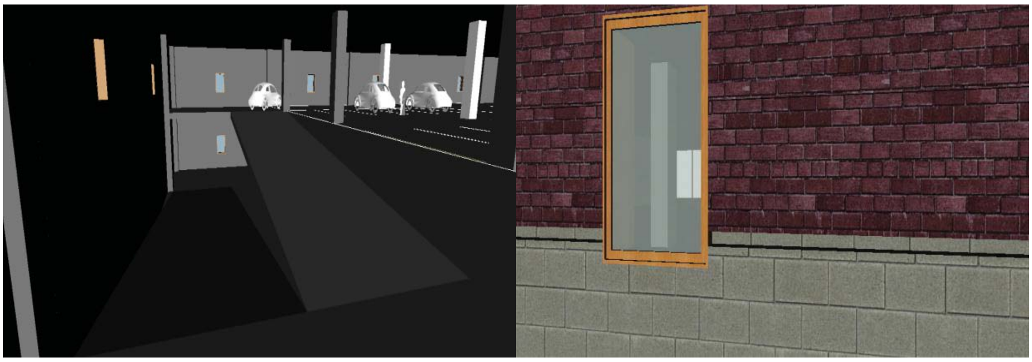

Fig. 5: 3D view of ramps and brickwork

Brickwork as also shown in Figure 5 could also be shown in detail to make workers grasp how and what sort of quality is needed when adjusting among window fixtures. In Figure 6, a parking space marking has been elaborated in a 3D BIM environment which will help the supervisors elaborating the space by using the dimensioning tools in a 3D environment. In addition, it can also help the supervisors to put in the picture the position of parking security gates alongside overhead rolling provide at entry and exit points.

Figure 6: Dimensioning tools in visualization in BIM Environment

CONCLUSION

The study discussed the rich aspects of BIM usage in order to educate the low skilled workers. Although limited up to now, it reinforces the fact that visualization application of BIM could be used for elaborating the construction product to the less educated and less skilled workforce in order to realize the future tasks. The 4D simulation of future construction tasks in detail with each individual construction element/activity (for e.g. in case of a masonry wall; simulation showing activities of lining, brick layering, adjustment to openings and final joint works) will help the supervisors on construction sites to elaborate the works easily to the lower hierarchy. Simulation videos in local languages might reduce the rework in addition to quality enhancement where the language should not be the main function of the instruction, but rather the 4D visualization. This is just showing that we stay at the very beginning of the research to look for different suitable ways to specifically train workers for their on-site works. More innovative ideas will come up with the use of BIM and BIM models for better employability and teaching of low-skilled construction laborers in order to perform construction tasks with fewer difficulties as compared to the present scenario.

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A DYNAMIC AUTOMATED SYSTEM FOR SITE LAYOUT PLANNING IN EGYPT[1]

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ABSTRACT: *Allocating an optimal space for resources and facilities in the construction site before the project starts is a problem known as site layout planning, solving this problem is a challenging task. A construction site with a well-planned layout could lead to minimizing the transportation time and cost for labour and materials, increasing in the productivity as well as work quality, improvement in the safety, reducing the harmful effects on the surrounding environmental. Construction sites in Egypt often neglect or overlook the site layout planning task and do not consider it as a basic task that must be performed which lead to inefficient layouts. Although a lot of automated site layout systems had been developed, these systems even have some shortcomings, limits or hard to apply in real construction sites in Egypt. The aim of this paper is to introduce the components for a dynamic automated system which is capable to perform the task of site layout based on Genetic Algorithms (GAs) as optimization engine and Computer Aided Drafting (CAD) for graphical representation to overcome the limitations of other developed automated systems.*

KEYWORDS: *automated systems, dynamic planning, construction sites, site layout planning.*

❖ INTRODUCTION

Site space is considered a limited resource in construction projects. Different facilities (e.g. batch plant, tower crane, material storage areas, working areas) exist on a site to support construction activities. These facilities arrive to the site at different points of time and occupy space on the site for different durations (Andayesh and Sadeghpour 2013). Allocating an optimal space for these facilities in the construction site before the project starts is a problem known as site layout planning (Liggett 2000 and Akinci, et al. 2002). Choosing this optimal space in construction sites subject to some predefined constraints (such as boundary and overlap constraints) to achieve predefined objective(s) (such as reduction in project cost or time, improvement in safety and protect surrounding environment). However, the current practices in most projects that the process of the site layout planning is ignored in the planning phase and often done in the site by the project manager by adjusting previous layouts based mainly on the project manager's experience, common sense and the famous concepts what come first serve first in addition to inadequate staff or time and based on incomplete and ill structured information (Sadeghpour 2004 and Sanad, et al. 2008). This may lead to generating inefficient layouts which have bad influence on the overall site operation (Sadeghpour 2006).

Despite the potential benefits from the site layout planning process but planners consider it a heavy duty process to be done because it needs a lot of complex information from different sources which vary for each project. Furthermore, there is a huge trade-off between its objectives. In addition, it's a difficult step to update the layout manually. As well as it's very expensive and time consuming process to make corrections in the layout to solve a problem after the project starts. Therefore, automated site layout systems are essentially required to give the site mangers and planners the capabilities to develop, modify or update the site layouts (Said and El-Rayes 2013 and Sadeghpour 2004). The automated site layout systems can be developed based on two approaches: static and dynamic planning. The static layout planning means creating a layout to keep the facilities that serve in different construction phases during the whole project fixed in size and location (Ning, et al. 2010). While the dynamic layout planning means creating a layout that reflects the change in construction activities on the facilities as the project's phases progress (Issac, et al. 2012). Although a lot of automated site layout systems had been developed, these systems even have some shortcomings, limitations or being hard to apply in real construction sites.

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Site layout planning in the Arab Republic of Egypt is neglected or overlooked in large segment of the construction sites although the recognition of its importance and the significant impact on the project cost and time which was experienced by site visits. Furthermore, A study conducted by Masoud (2010) for the construction sites in Egypt indicates that 73% of the project managers and site engineers put a site plan but the mostly are not documented, as 9% of them said they don't draw up a plan, while 18% said that they would often draw up a plan according to the size, importance of the project and the movement of equipment and employs in the site. Furthermore, few researchers directed their efforts towards developing the site layout planning area in Egypt. The objective of this paper is to present the components for an automated system capable of performing the task of site layout planning in allocating a space for the temporary facilities, which serve in the construction site. This system is proposed to overcome the limitations of other developed automated systems and to obtain the real life demand based on the finding from literature review.

LITERATURE REVIEW

There is a long history of research into automated systems in the construction site layout planning. Amongst the first efforts were those utilizing mathematical optimizations in the automated systems, but few of these systems was successful and even then, these systems were rigid and worked only for the specific case they were built for as well as for small projects (Tommelein 1992 and Sadeghpour, et al. 2006). Later, the developed automated systems gradually moved to depend on the heuristic methods. Due to the combinatorial nature of the site layout problems the heuristics techniques advised to be suitable practical solution. The current direction in research for site layout planning problems is developing more suitable systems which take into consideration the time element with multiple criteria for evaluation (Mawdesley, et al. 2002). The rest of this section will illustrate some of the developed automated systems.

Yeh (1995) introduced the SitePlan which is a site layout model that applies a hybrid type of Neural Networks (NN) called Annealed Neural Networks (ANN). Annealed Neural Networks inherits features of both NN and simulated annealing. SitePlan represents site layout as a problem of finding the best location for a set of equal size rectangles in a set of predetermined locations on site. This representation is obviously an extreme simplification of the reality of construction sites where facilities come in all shapes, sizes and can be placed anywhere on the site.

However, Elbeltagi, et al. (2004) present a model for dynamic site layout planning in construction using genetic algorithms optimization that assists in maintaining safety and productivity on construction sites with important consideration for the cost of reallocation of temporary facilities. However, representation of the temporary facilities have been much simplified and facilitated. The method used in calculating the distance between the facilities (Euclidean: center-to-center distances) do not express the real distance in real life which governed by actual site paths.

In addition, Sadeghpour, et al. (2006) proposed a static model based on knowledge based system to solve construction site layout planning problems. The developed model performs its task at two levels: Site representation, and site space analysis and allocation. However, this model needs an expert and huge database to enhance its capability.

Besides that, Khalafallah and El-Rayes (2011) introduced a static multi objective automated system based on Genetic Algorithms optimization to provide practical automated support for construction planners and airport operators who need to optimize site layout plans. However, the model have some limitations including: (1) modeling temporary and existing facilities using two-dimensional rectangles, (2) approximating resource travel paths as the center-to-center distance between site facilities, and (3) assuming that site space requirements are predetermined and static, (4) intense specialization in one type of projects (airport project).

Later, Xu and Li (2012) developed a fuzzy random multi-objective decision making model. In this model, two objectives are considered: (1) minimizing the total cost of site layout; and (2) maximizing the safety to avoid accidents. A multi-objective particle swarm optimization algorithm (MOPSO) with permutation-based representation is proposed to solve the optimization problem. But this model deals with the site space as equal area problem and utilize only two kinds of constraints which doesn't happen in real projects.

Furthermore, Ning and Lam (2013) designed a multi-objective optimization (MOO) model using modified Pareto-based ant colony optimization (ACO) algorithm. The two objectives used in this model were reducing the cost and improve the site safety level simultaneously while solving unequal-area site space problem. It used to give static layouts with little number of facilities.

As well as, Said and El-Rayes (2013) presents and compares between two global optimization models of dynamic site layout planning that were developed to overcome the limitations of previous models. The first model utilizes Genetic Algorithms (GA) while the second model utilizes Approximate Dynamic Programming (ADP). Both developed models have a single objective and deal with the site space as equal area problem which consider huge drawbacks.

Despite the contributions of the aforementioned site layout planning systems, they still have drawbacks such as, they are limited to one or two objectives, 2D rectangular shape only, need expert to use, rigid and comprised for limited or fixed elements such as facilities and constraints, consequently, they cannot be applied for other cases but only the case they are modelled for. Also these models are rarely covering the real sites demand or built on real factors measured from sites (such as distance between facilities). In addition, the previous research work on site layout have mainly ignored the user interaction and concentrated on selecting information from their data base. Furthermore, it is not acceptable nowadays to generate a static layout for a project, deals with the site space as equal area problem or develop single objective model, because it is contrary to what happens in reality.

However, so far, there are limitations and drawbacks that are not covered or solved, thus there is need for developing recent model. Therefore, based on findings and contribution from literature review this paper will introduce the components for a dynamic automated system to perform the task of site layout based on Genetic Algorithms as optimization engine and Computer Aided Drafting for graphical representation.

THE PROPOSED AUTOMATED SYSTEM

The proposed automated site layout planning system will support construction planners in identifying the optimal locations for all temporary facilities on construction sites by using the dynamic site layout approach. The dynamic layout for the whole project duration will be generated in two stages. Firstly, the project duration is subdivided into successive stages and a static layout is generated for each stage and each stage is considered completely separate. Secondly, dynamic layout is performed by taking layout continuity into consideration.

The proposed system will be designed to provide a number of unique and practical capabilities, including: (1) utilizing multi-objective genetic algorithms in order to enable the simultaneous optimization of construction cost, time, safety and environmental impact; (2) huge user interaction in adjusting or adding data and in selecting the desired objective (single or multiple objectives with the percentage trade off); (3) model the available site space as unequal area layout problem; and (4) supporting the visualization of the generated optimal 4D site layout plans through seamless integration with commercially available CAD software systems.

In order to provide the aforementioned capabilities, the system will be implemented and integrated into four main components:

1. A comprehensive multi-objective optimization engine that integrates and optimizes the overall impact of site layout planning on construction cost, time, safety and environmental impact.
2. A database library to support storing and retrieving construction site layout data and the generated optimal solutions.
3. An input module that facilitates the input of project data.
4. An output module retrieval of the generated optimal 4D site layout solutions and visualize them using commercially available CAD software systems, as shown in Figure 1. These four system components are described in more details in the following sections.

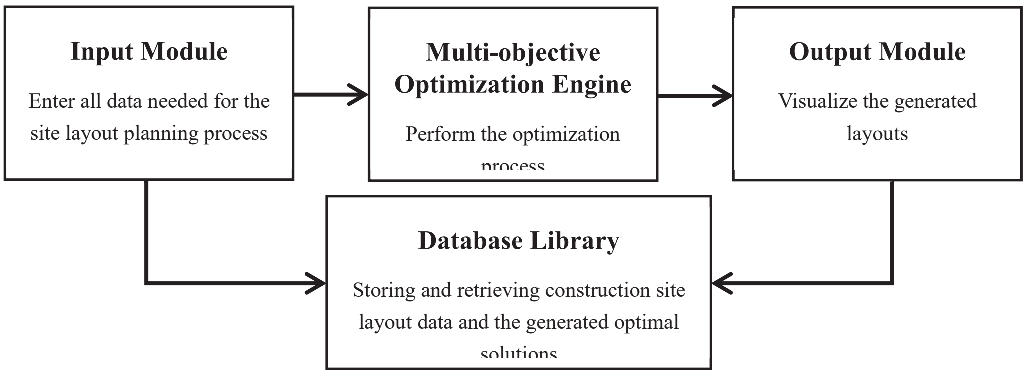

Fig. 1: Main component of the proposed automated system.

Input Module

The function of this system component is to enable the user to enter all data needed for the site layout planning process. The data used in the system can be grouped into five major categories as shown in Table 1.

Table 1: Description of the main data types required in the automated system.

Data	Description
Project data	Main project information (name, company, duration….). Main project stages and their duration grouped based on temporary facility requirements.
Geometrical data	CAD drawings representing the site boundary, site paths, fixed facilities locations in each project stage and the different site area.
Facilities data	Different facilities requirements for project activity in each stage in addition to the expected sizes of these temporary facilities.
Constraint data	Required constraints.
Required objective data	The required objective (single or multiple objectives with the percentage trade off).

The following three sections provide a detailed description about the developed data used for the construction site facilities, site area and the space constraints in the proposed automated system:

Construction site facilities

The Construction site facilities were previously classified by many authors such as Elbeltagi (1999) into two categories and Mawdesley, et al. (2002) into four categories. However the construction site facilities will be classified and defined in the proposed automated system into three main categories as shown in Table 2.

Table 2: The construction site facilities categories.

Category	Description
Fixed facilities	Are those facilities with predetermined fixed positions on site such as the constructed or existing building, paths and obstacles. Planners do not need to select the locations of these facilities as their positions and dimensions are predetermined and can be extracted from the construction drawings.
Static facilities	Are temporary facilities that need to position just one time then their positions remain fixed such as tower cranes and batch plants. These facilities are not allowed to be repositioned on site in later project stages due to the significant time, cost, and/or effort required to relocate them.
Dynamic facilities	Are temporary construction facilities that can be relocated at the start of any of the identified project stages. Examples of dynamic facilities include site offices, testing laboratories, storage areas and fabrication areas. A dynamic facility can be relocated in cases where there is new free space became available that is better than its currently occupied location, or if other new facilities need to position in its current location for more layout improvement. The ability to modify the locations of the dynamic facilities in different project stages can improve the efficiency of the overall site layout. However this repositioning must account for additional relocation cost.

Construction site areas

The aforementioned facilities need to be assigned to the construction site boundary which is classified into two different types of areas: available areas and unavailable areas. The available area is the area that construction site facilities (static and dynamic facilities) can be positioned. The unavailable area is the area that not suitable for positing the construction site facilities, it could be the area occupied with the fixed facilities or the area defined as protected zone for the safety and environment consideration (Easa and Hossain 2008 and Mawdesley, et al. 2002) Figure 2. These areas will be defined by the automated system users using the site drawing according to each site conditions and demands.

Site space constraints

The site space constraints it is a set of rules used to govern the process of positing the facilities (Sadeghpour 2004 and El-Rayes and Said 2009).Although the site layout planning task can be done by less number of constraints as modelled before such as El-Rayes and Khalafallah (2005) that used two constraints and El-Rayes and Said (2009) that used four constraints. However, the site space constraints in this proposed automated system will offer a classification of five main categories to cover all the constraints that may be required by users as detailed in Table 3.

Table 3: The site space constraints.

Constraints	Description.
Boundary constraints	Are examined in this model for each solution in order to ensure that the static and dynamic facilities are located within the boundaries of the site (El-Rayes and Khalafallah 2005).
Overlap constraints	Are examined in this model for each solution in order to ensure that no overlap occurs between any pair of facilities on the same construction stage (El-Rayes and Khalafallah 2005).
Adjacency or closeness constraints	Imposed for the reason that some facilities may be required to be adjacent or close to other, or may have to be away from other to satisfy operational, safety, security and/or environment requirement in site (Easa and Hossain 2008 and El-Rayes and Said 2009).
Zone constraints	Imposed for the reason that some facilities should be located or not in a specific zone to satisfy safety or environment requirements in site (Easa and Hossain 2008 and El-Rayes and Said 2009).
Visibility constraints	Imposed for the reason that some facilities may be required to be visible from a specific location in the construction area such as a gatehouse (Easa and Hossain 2008).

Multi-objective optimization engine

The function of this system component is to perform the optimization process in order to allocate an optimal place for all needed facilities according to the specified weighted objective by the user from the available three site layout objectives: (1) minimize construction cost, (2) minimize construction time, (3) maximize construction safety in site while preventing any harmful impact on the surrounding environment, while taking into account the imposed constraints. The optimization process run based on the Genetic Algorithms (GAs) optimization technique. This technique was chosen based on results from previous research which showed that GAs are robust, with huge ability to deal with inexact, missing, or poorly defined problems, and have the capability to efficiently search complex solution space. As well as it is easy to model and perform very efficiently in multi objective optimization layout problems (Said and El-Rayes 2013). Furthermore the Genetic Algorithms technique act effectively in global solution search optimization (El Ansary and Shalaby 2014)

Genetic Algorithms belong to evolutionary algorithms that are based on the natural selection and genetics to search through decision space for optimum solutions. GAs generate a random yet directed search for locating the globally optimal solution. Usually, a solution is represented as a linear string called chromosome whose length varies from one application to another. Some measures of fitness (objective function) are applied to construct the process of new solutions' generation. Once the chromosome structure and the objective function are set, the GAs evolutionary procedure takes place on a population of parent chromosomes. Three genetic operations are required: Selection, crossover, and mutation (Sanad, et al. 2008).

Selection is the process by which chromosomes with better fitness values receive correspondingly better copies in the new generation. As the total number of chromosomes in each generation is kept constant, chromosomes with lower fitness values are eliminated. The second operator; crossover, is the process in which chromosomes are able to mix and match their desirable qualities in a random fashion. Crossover (marriage) is conducted by selecting two parent chromosomes, exchanging their information, and producing offsprings. Mutation is a process that resembles the process of a sudden generation of an odd offspring that turns out to be genius (Goldberg 1989 and Sanad, et al. 2008).

Output module

The function of this system component is to retrieve the generated optimal 4D site layout solutions and exports them to external CAD software in order to provide construction planners with the capability of visualizing the generated optimal site layouts.

Database library

The main function of this system component is to store the all necessary site layout input data and the generated optimal 4D site layout plans.

SUMMARY AND FUTURE WORK

This paper presented the components for a dynamic automated system to perform the task of site layout based on Genetic Algorithms (GAs) as optimization engine and Computer Aided Drafting (CAD) for graphical representation. The four main components are: (1) A comprehensive multi-objective optimization engine, (2) A database library, (3) An input module, (4) An output module. The introduced components were described in details and developed based on reviewing all previous work to overcome the limitations.

The proposed work is a part of a research scheme; therefore it is a summary of the first phase of this research which is totally based on literature review. In the advance stages the research is going to define and analyze the real construction sites' demand in Egypt. Then the construction sites' demand will be analyzed with the considered components from literature to setup the final framework and structure for the proposed automated system that will take place. Furthermore, the automated system will be developed. Later, the developed automated system will be tested for efficiency and validated for applicability in real life.

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USING VIDEOS TO CREATE SEMANTIC VIRTUAL CONSTRUCTION[1]

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ABSTRACT: *In current practice, it is difficult for engineers to dynamically re-plan space usage since the location and quantity of onsite resources change over time. Though several researchers have developed site cameras to facilitate dynamic space management, using camera in the site still has fragmentation between site monitoring and planning. In this research, we aim to rapidly retrieve geometric information from site cameras for dynamic site planning. We developed a four-step method: projection, duplication, description and calibration. The first step, projection, is to establish the projective model of the camera between videos and actual site. The second step, duplication, is to rapidly acquire positions and dimensions of construction objects based on the images from video frames and model their 3D geometry in geometric virtual construction. The third step, description, is to link the geometric models with the real objects and build semantic virtual constriction, which contains not only onsite scenarios but also engineers' knowledge. The fourth step, calibration, is to improve the accuracy of the virtual construction for realistic planning. We built a software tool by integrating the four steps, which allows engineers to load the video and specify the location and the meaning of each object. The algorithms are simultaneously creating the numerical models to link the images on the video with the virtual models. We used a real campus building to validate the usability of our method. Using the CCTV videos retrieved from the site, it took 123 seconds to create a virtual construction site. We compared the actual objects with virtual ones and found the errors are from 0.2 to 1.2 meters. The results indicate our method is feasible to transfer video to numerical virtual construction site within a reasonable time and accuracy.*

KEYWORDS: *Site layout planning, dynamic site, virtual construction, cameras, geometry, real-time, simulation.*

❖ INTRODUCTION

Construction site layout planning is one of the most important preliminary tasks in a construction project. To accommodate limited site space, plans must be made for aspects such as the location of facilities, space for traffic, and accessibility of vehicles (Zouein et al., 2002). The layout problem is an important issue because it can significantly affect safety, efficiency, and other aspects of the project (Easa and Hossain, 2008; Su et al., 2012; Xu and Li, 2012). In particular, the issues of location of heavy equipment and vehicle access are two common problems encountered in construction projects due to limited space (Yang et al., 2013), and thus are critical concerns.

However, site layout is not static, since the resources at a site change over time. Planning a complete site layout in a dynamic situation thus can encounter more difficulties than in a static situation. When engineers design the layout plan of a dynamic site, they need to be able to quickly accommodate on-site aspects such as temporary facilities and equipment given only limited space (Andayesh and Sadeghpour, 2013). For this purpose, a quicker and deeper understanding of construction activity information in real-time is needed (Cheng and Teizer, 2013).

Nowadays, the camera techniques are increasingly applied to construction management. Methods employing site images and videos are commonly used to provide real-time information for engineers. Nevertheless, these tools for construction management have a long-standing problem: fragmentation between site monitoring and planning. Cameras can only provide qualitative space descriptions, such as left, right, far, and near. It is difficult for engineers to directly obtain quantitative space data about distance or position. Engineers using qualitative descriptions of space usage readily leads to integrity issues in site planning (Akinci et al., 2002).

The major challenge of dynamic layout planning is how to rapidly retrieve quantitative space data from cameras. Cameras are common at current construction sites. If engineers can unitize quantitative dimensional and locational data from cameras immediately, this spatial information will help them to plan the site layout before each actual operation. In other words, the integration of monitoring and data retrieval from cameras will expand the existing applications of on-site cameras and benefit dynamic site planning.

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[1]Citation: Liu, C. W., Kang, S. C. & Huang, S. M. (2014). Using videos to create semantic virtual construction. In: N. Dawood and S.Alkass (Eds.), Proceedings of the 14th International Conference on Construction Applications of Virtual Reality, 16-18 November 2014, Sharjah, UAE.

RESEARCH GOALS

The objective of this research is to rapidly retrieve geometric information from on-site videos to create a virtual construction site. We aim to retrieve necessary spatial data through on-site cameras, and to utilize the data to update virtual construction for visualizing a dynamic site. To be more specific, the method developed can facilitate the achievement of the following goals:

(1) *Acquiring real-time spatial data from on-site videos*: The spatial data including positions and dimensions of construction objects need to be retrieved rapidly. The real-time data will help engineers to understand the situation at a site and perform re-planning immediately.

(2) *Building reliable virtual construction for planning:* The virtual construction, which contains accurate spatial information and ideas of engineers, needs to be reliable for planning. It will help engineers to visualize on-site scenarios and carry out re-planning precisely.

In this research, the two elements above are developed and integrated as a software tool. Utilizing the developed tool, engineers are able to perform re-planning during site operations rather than before starting. For example, they can update and arrange the site layout before every task, or deal with sudden events through the on-site video to operate the layout in a reliable virtual construction. Essentially, engineers can retrieve necessary information through the on-site video and re-plan the site operations at any given time.

METHODOLOGY

In this research, we developed a four-step method to build a semantic virtual construction for dynamic site planning. A description of the system and each step is given in the proceeding sections.

System overview

The four steps in the developed system are projection, duplication, description, and calibration (Fig. 6).

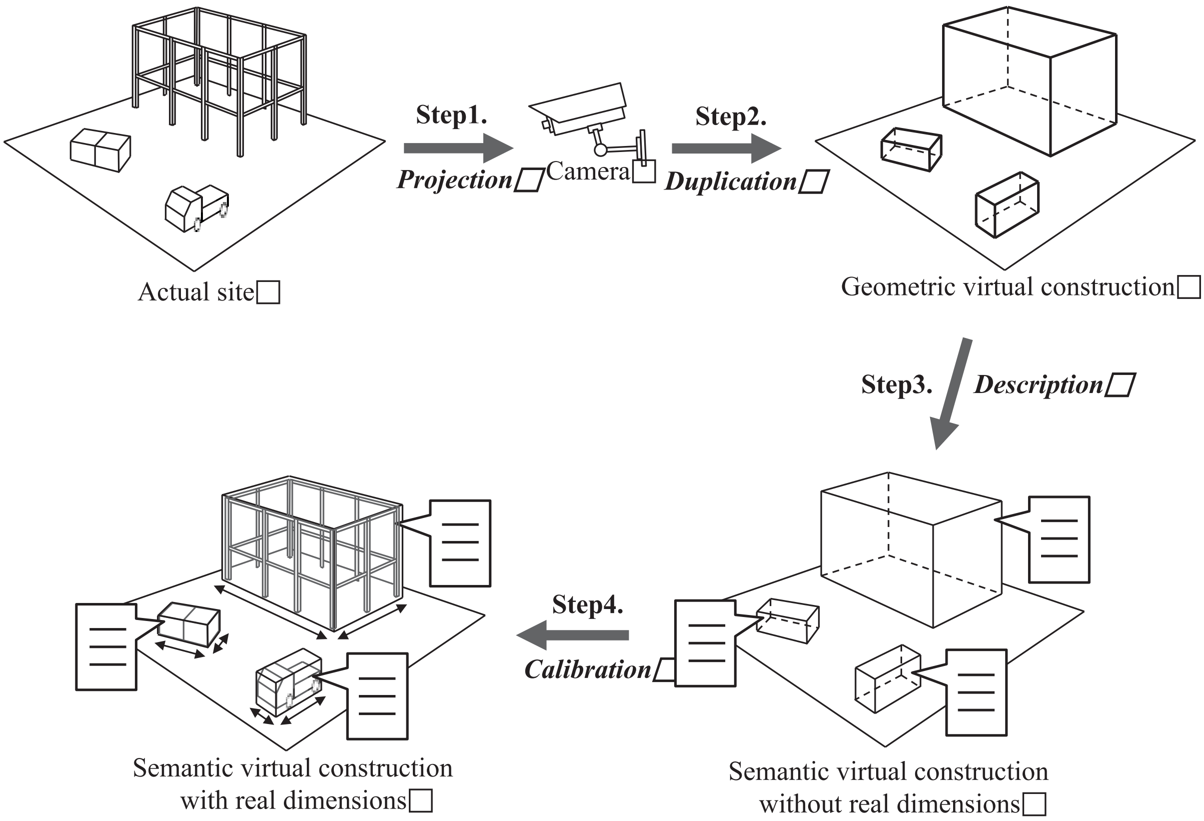

Fig. 6: The four steps in the developed system: projection, duplication, description, and calibration.

The first step, *projection*, aims to establish the projective model of the camera by using an on-site video and a site map. It enables engineers to transform image coordinates to site coordinates of the objects displayed on the image. The second step, *duplication*, aims to build a geometric virtual construction based on actual scenarios. It enables engineers to model on-site objects using previous projective transformations. The third step, *description*, aims to link the geometric models with the real objects to build a semantic virtual construction that contains ideas of engineers. It enables engineers to assign meaning to virtual objects for site understanding and recognition. The fourth step, *calibration*, aims to adjust the acquired spatial data when engineers assign the actual dimensions of the objects, which can improve the accuracy of the virtual construction for correct planning.

First step: *Projection*

In the first step, we aim to establish the projective model of on-site cameras such as CCTV (Ju et al., 2012 and Kim et al., 2013). Since camera projection can be regarded as a coordinate transformation from the real world to an image, it is theoretically possible to obtain real position coordinates based on a camera projection. As long as the transformation of the on-site camera is defined, it can be used to compute every corresponding point between the real world and the image. We can then transform the position coordinates from the image and calculate the distance between any two points.

To compute the camera projective transformation, we first considered a model of a camera (Fig. 7). The effects of focus and lens thickness were ignored. After engineers record a video or take a photo using an on-site camera, point P_O of an on-site object at the construction site can be mapped to a corresponding point P_I on the projected image such as a CCTV video image. Fig. 7 also shows a projective transformation between the plane of object space (XY-system) and the image plane (UV-system).

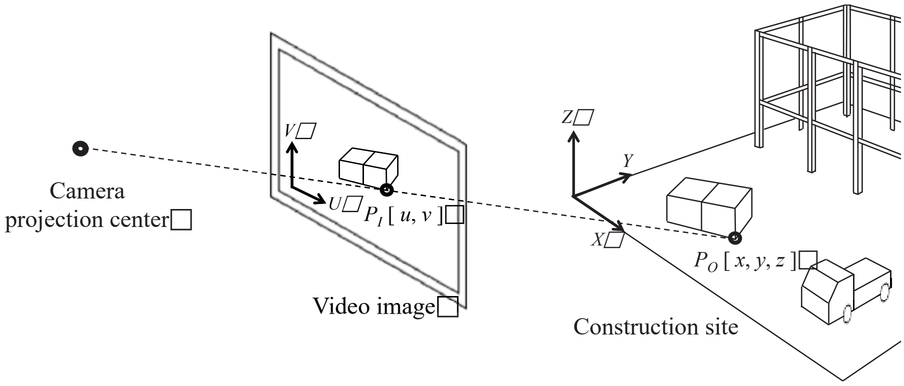

Fig. 7: A model of a projective camera between construction site and video image.

If we focus on the points that lie on a flat site ground (e.g., z = 0), the action of a projective camera from the site to an image can be expressed in terms of a linear mapping of homogeneous coordinate as

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \mathbf{H}_{3\times3} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \tag{1}$$

, where $[\,u \quad v \quad 1\,]^T$ represents the homogeneous image-plane coordinates of point P_I (UV-system), $[\,x \quad y \quad 1\,]^T$ represents the homogeneous object-space coordinates of point P_O (XY-system), and $\mathbf{H}_{3\times3}$ is a 3×3 matrix representing the projective transformation. Due to the camera projection, every real point (XY-system) on the ground has a one-to-one corresponding image point (UV-system) on the image plane. In other words, after determining the projective model of the camera and projective transformation $\mathbf{H}_{3\times3}$ from the video image, Eq. (1) can be used to calculate the real position coordinates of any point from the image.

Second step: *Duplication*

In this step, we aim to model on-site scenarios and build a geometric virtual construction. The position coordinates obtained in the previous step enable us to generate the geometric models in a virtual environment.

However, we have to import the 3-D models of a fixed scene to construct the basic virtual scene in advance for recognition. We suggest that this import should include models of existing buildings, fences, and terrain, which are fixed in the real environment. These features will assist engineers to recognize the location of objects following the virtual reconstruction. After importing a basic virtual scene, we can locate and measure the position and dimension data of required objects from the image in an on-site video frame using the previous data measurement method. For example, we can obtain the positions and dimensions of the bottom of trucks, obstacles, and buildings.

As $\mathbf{H}_{3\times3}$ is a plane-to-plane (e.g., ground to image) projective transformation, it can only be used to determine the on-the-ground position of the on-site objects that are on a flat site field. However, horizontal space is more seriously limited than vertical space at an outdoor construction site. More concern exists regarding the on-the-ground width and length of objects rather than their height during site layout planning. That is, the data of on-the-ground width and length is more beneficial than height. We can use these data to model the area of a working region by a virtual rectangle. For on-site objects, we can manually give a certain height to model them by a virtual rectangular solid, as shown in Figure 3. In short, we can model on-site objects and working areas of concern by acquiring positions and dimensions from an image in a video frame. Finally, all objects and working areas of interest can be modeled using their geometries and a virtual construction can be built.

Third step: *Description*

In this step, we aim to build a semantic virtual construction, which contains not only virtual scenarios but also engineer knowledge. The assignment of such knowledge to the virtual objects is important in this step.

After the geometric virtual construction is reconstructed in the previous step, engineers can assign properties such as name, type, and appearance to objects or working areas. For example, they can assign the name to an object or note the purpose to a reserved area, as shown in Figure 4. Geometric models can be assigned a role based on the actual site (e.g., trucks), while abstract spaces can be designated by a visual representation (e.g., working areas). The described objects will assist engineers to identify the usage of space during planning. This step can make virtual construction more intuitive and understandable than a pure 3D virtual environment permits.

Engineers can start to plan a site layout in the semantic virtual construction after describing the meaning of objects. The planning in the semantic virtual construction can be assumed to be reliable because all objects are modeled based on images in on-site video frames. Engineers can optimize layouts by rearranging objects in the virtual environment rather than repeatedly moving the actual objects in the real world.

Fourth step: *Calibration*

In this step, we aim to improve the accuracy of the semantic virtual construction that was built in the third step. When engineers assign a role to an object, its known dimensions can be used to calibrate the projective model developed in the first step. For example, the length and width of a piece of equipment can provide known dimensional information as additional equations to solve the projective transformation matrix $\mathbf{H}_{3\times3}$.

We consider a simple object shown in Fig. 8, where P_1, P_2 and P_3 are the corners of the bottom of the object, L is the distance between P_2 and P_3, W is the distance between P_1 and P_2, and θ is the angle between P_1, P_2 and P_3. Realistically, only these three corners are visible in the image of a given object.

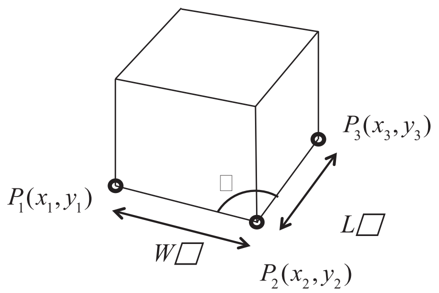

Fig. 8: The geometric relationship of a simple object with known dimensions on the image.

The coordinate of P_1 has a geometric relationship with P_2, P_3, W, L and θ:

$$\begin{bmatrix} x_1 \\ y_1 \end{bmatrix} = \begin{bmatrix} x_2 \\ y_2 \end{bmatrix} + L \begin{bmatrix} \cos\left(\theta + \tan^{-1}\left(\frac{y_3 - y_2}{x_3 - x_2}\right)\right) \\ \sin\left(\theta + \tan^{-1}\left(\frac{y_3 - y_2}{x_3 - x_2}\right)\right) \end{bmatrix} \tag{2}$$

, where $\tan^{-1}\left(\frac{y_3-y_2}{x_3-x_2}\right)$ can be considered the orientation angle of P_2 and P_3. P_3 has the same geometric relationship with P_1 and P_2. Based on these equations, we can find an additional point correspondence, P_1 (x, y) and its image coordinates (u, v), for any object with known dimensions. These additional point correspondences can be used to calibrate $\mathbf{H}_{3\times3}$.

IMPLEMENTATION

In this research, we integrated the four-step method and implemented a software tool. We employed Unity3D[1] as the main platform, which enabled us to integrate videos and virtual construction in the system. We also used a video of an on-going construction project in Taipei, Taiwan as a source for example images. This site covers a flat field with an area of approximately 31,000 m^2, and contains various working areas and material areas (Fig. 9).

For the first step, *projection*, at least four control points with known real-world location coordinates are needed. In general, the corners of fences and existing buildings are ideal control points because they can be easily detected in images and, more importantly, their positions always remain fixed. With this in mind, we selected the corners of fences, gates, and fixed objects, shown in Fig. 9. We can easily obtain their real position (x and y) from the site maps or 2-D drawings, and we can obtain the image coordinates (u and v) from a video. All the coordinates are shown in Table 3. These coordinates can be used to solve $\mathbf{H}_{3\times3}$, which is the camera projection matrix

Fig. 9: An example video of a construction project, which contains various working areas and equipment. We selected four control points (A, B, C and D) in this case.

Table 3: The real position (x, y) and image coordinates (u, v) of the control points in the example video.

Control points	Real Position (m) (x, y)	Image Coordinates* (pixel) (u, v)
A	(5.0, 5.0)	(301, 70)
B	(65.0, 0.0)	(74, 107)
C	(49.0, 130.0)	(330, 316)
D	(0.0, 110.0)	(608, 154)

* The resolution of the video image is 720x405 pixels and we set the orgin at left-top.

In the second step, *duplication*, the 3-D models of existing buildings, fences, trees, and terrain need to be imported in advance in order to aid engineers in recognizing the construction site. The integrated interface of the developed tool in Unity3D is shown in Fig. 11. The region on the left was obtained from the on-site video and the region on the right shows the virtual construction with a basic virtual scene. A controller such as a video player and modeling tools can be found in the bottom region.

In the on-site video, engineers can select an appropriate frame and sketch objects of concern using a mouse to acquire their positions and dimensions. These are modeled in the virtual construction simultaneously. Engineers can sketch the outlines of a working area to model the virtual rectangle. They also can sketch the bottoms of objects and then set the height manually to model a virtual rectangular solid, as shown in Fig. 10. These simple actions can transform image pixel data to position and dimension data for modeling a virtual object.

[1] Unity3D is a 3D game development platform that provides video supporting, real-time rendering, a graphical user interface, and networking, http://unity3d.com/.

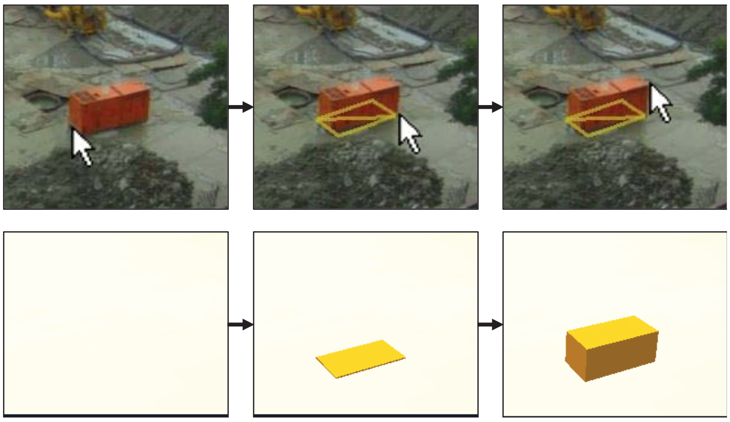

Fig. 10: The process of duplicating objects on the image by sketching its outline.

The interface as it appears after all working areas and objects are modeled in the virtual construction is shown in Fig. 11. Each plane and rectangular solid in the virtual construction is a representation of a working area or an on-site object in the real world.

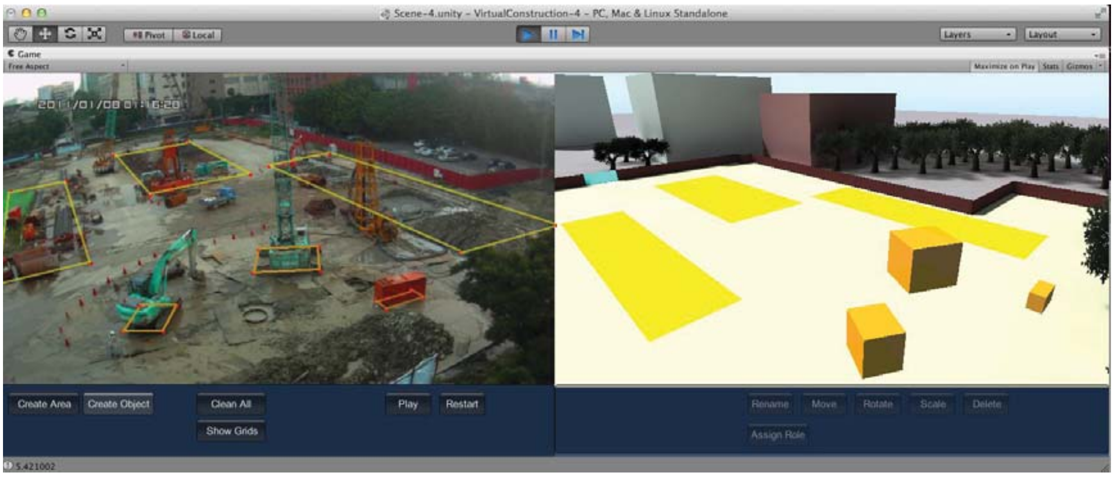

Fig. 11: The integrated interface of the developed tool. The left region is on-site video and the right region is virtual construction with various working areas and on-site objects.

In the third step, *description*, engineers can start to assign roles to objects such as excavators, cranes, and obstacles to create a semantic virtual construction. They can also move or rotate the objects as necessary to optimize the site layout. The rendering result of the semantic virtual construction is shown in Fig. 12. A crane and an excavator are deployed in the semantic virtual construction.

Fig. 12: The semantic virtual construction with various working areas, a crane and an excavator.

In the final step, *calibration*, engineers can improve the accuracy of the virtual construction using the given dimensions of the objects. The $\mathbf{H}_{3\times3}$ matrix can be calibrated by actual dimensions when engineers duplicate an object based on its outline on the image. For example, when engineers duplicate the crane and input its dimensions, this information will produce additional equations to solve the calibrated $\mathbf{H}_{3\times3}$ via the Least Squares Method. By making use of more given dimensions of different objects, accuracy is likely to improve because the increased samples can minimize the sum of the squares of the errors made in the results of each equation.

In the example case, we implemented *calibration* and *description* at the same time. For example, when engineers assign a virtual object as a crane, the tool will use the positional and actual dimensional data of the crane to calibrate $\mathbf{H}_{3\times3}$. The virtual construction will be updated by the calibrated $\mathbf{H}_{3\times3}$ matrix with more precise spatial information.

VALIDATION

In this research, we evaluated the efficiency of creating a virtual construction site and the accuracy of the model. The required time during the creation of the virtual construction is shown in Table 4. In the example case, the real positions and image coordinates of the four control points were measured before planning, and the basic 3-D scenes were imported in advance. In the first step, *projection*, the projective matrix $\mathbf{H}_{3\times3}$ was computed in a few seconds since the computation is not overly complex for a computer. In the second step, *duplication*, the average time of sketching six on-site objects on the video and duplicating them into the virtual construction was about 42.9 seconds. In the third step, *description*, the average time of describing six objects was about 60.2 seconds. In the fourth step, *calibration*, the average time of translating the virtual model to the correct position and assigning actual dimensions was about 20.5 seconds. In summary, the average time taken to completely build the on-site scenario considered was 123.6 seconds. It is thus possible to acquire spatial data from on-site videos in near real-time during real operations.

Table 4: The required time to build virtual construction in the example case.

Step	**Average time (second)**
Step 1. projection	Few seconds in computer
Step 2. duplication	42.9
Step 3. description	60.2
Step 4. callibration	20.5
Total time	123.6

The accuracy of the spatial information of the developed virtual construction is shown in Table 5. The errors between the actual length and the acquired length from the image ranged from approximately 0.2 to 1.2 meters, or 2% to 20%. A virtual construction with reliable spatial information thus appears feasible to build for planning purposes. Further, the results of the fourth step, *calibration*, are shown in

Table 6. We found that calibration could increase the accuracy of the acquired lengths but it was still difficult to exactly match all the objects to their actual lengths.

Table 5: The accuracy of acquired spatial length without calibration.

Object dimensions	**Actual length (m)**	**Acquired length (m)**	**Error (m)**	**Error (%)**
Length of the gate	9.00	8.78	-0.22	-2.40%
Length of the excavator	5.46	5.70	0.24	4.40%
Width of the excavator	3.57	4.30	0.73	20.45%
Length of the crane	7.90	9.10	1.20	15.19%
Width of the crane	6.31	6.50	0.19	3.01%

Table 6: The results of calibration by an excavator and a crane.

Object dimensions	Actual length (m)	Calibration by an excavator			Calibration by a crane		
		length (m)	error (m)	error (%)	length (m)	error (m)	error (%)
Length of the gate	9.00	8.72	-0.28	-3.1%	8.87	-0.13	-1.4%
Length of the excavator	5.46	5.58	0.12	2.2%	4.85	-0.61	-11.2%
Width of the excavator	3.57	4.22	0.65	18.2%	3.62	0.05	1.4%
Length of the crane	7.90	8.98	1.08	13.7%	7.70	-0.20	-2.5%
Width of the crane	6.31	6.41	0.10	1.6%	5.72	-0.59	-9.4%

DISCUSSION

Based on the example tests, we found the factors influencing accuracy and the corresponding limitations in the model's current state of development. Our findings are summarized below:

(1) *Factors influencing accuracy*: The accuracy of the $\mathbf{H}_{3\times3}$ matrix that represents a projective transformation of a camera has a great influence on the accuracy of data acquisition. The accuracy of $\mathbf{H}_{3\times3}$ is affected by the quality of video and the control points selected.

The quality of the on-site video is a significant factor. A clear resolution of the on-site video is needed to recognize each control point on the image in a video frame and determine the UV coordinates of the control points and compute $\mathbf{H}_{3\times3}$. Further, the quality of the video also affects an engineer's ability to detect objects on the image. If a moveable object is blurred on the video frames, it is difficult to sketch the outline of the object and acquire accurate positional and dimensional data.

The selection of control points on an image in a video frame is another important factor. If the distribution of the control points is uniform on an image, it can improve the accuracy. On the other hand, the selection of control points that are concentrated or collinear on an image must be avoided. During our testing, we found an image point located farther away from control points has a larger potential for error in the position transformation. Distortion of the plane by the camera lens is another possible source of error. For this reason, we must calibrate $\mathbf{H}_{3\times3}$ when assigning known dimensions, which can provide addition control points to improve the accuracy.

(2) *Limitations at an actual site*: The tool developed is suitable for a site with a flat ground, as the assumption of the developed data acquisition method is a plane-to-plane transformation by camera projection. If there are objects at different elevations at the site, a sufficient number of control points should be used to compute the respective $\mathbf{H}_{3\times3}$ matrix, or different cameras should be employed to compute the respective transformation of each site ground.

The method developed cannot acquire the height of the construction objects using a single camera; engineers have to manually provide the height of virtual objects when reconstructing virtual scenarios. In this research, only one camera was used to simplify the photogrammetric method. Accordingly, we sacrificed the height data but with the advantage of speeding up the computation to real-time. However, in most outdoor site planning, the limitation of the height of objects is seldom of concern. Instead, horizontal limitations such as the on-the-ground length and width of on-site objects are more relevant.

In addition, the tool developed is suitable for a site with a fixed camera. If the position or direction of the camera changes, the UV coordinates on the image will require adjustment, and the $\mathbf{H}_{3\times3}$ matrix must also be updated at the same time. However, CCTV cameras with individual fixed positions and directions are common at construction sites. We can easily solve the $\mathbf{H}_{3\times3}$ matrix of each fixed camera to apply in the developed data measurement method. On the other hand, extra computation to permit automatic recognition of control points is needed if unfixed cameras are to be applied.

CONCLUSION

In this research, we created a new method to retrieve geometric information from on-site videos for building a virtual construction site. This research addresses the critical problem of the integration of monitoring and data retrieval from cameras. We used the Unity3D game engine to implement the method developed, which permits engineers to acquire real-time spatial data from on-site videos and build a reliable virtual construction for planning. We also proposed the concept of semantic virtual construction, whose meaningful virtual scenarios can reflect realistic site situations that are readily apprehensible. We used a video from an actual construction site as an example scenario. The results showed that the required time to build a semantic virtual construction using this model is approximately 123 seconds, demonstrating its workability to rapidly acquire on-site data from videos and accordingly update virtual construction for re-planning. In addition, the accuracy of the virtual construction ranged from approximately 0.2 to 1.2 meters, suggesting reliability for basic layout planning in terms of space usage.

The main contribution of this research is a novel method to retrieve necessary spatial information from on-site videos to assist with dynamic site planning. The data acquisition method developed, which can transfer visual data to numerical data for computing the sizes of objects and available space, allows engineers to utilize on-site video as a data collection tool. The virtual construction developed provides a visualization approach for rapid layout planning and simulation of the actual construction process. Engineers can examine time and space dimensions of the site simultaneously via videos and virtual construction and can attempt to find the optimal layout by actually participating and performing the layout rearrangement in the virtual environment. In summary, the tool developed permits engineers to rapidly re-plan site operations in a semantic virtual construction rather than at an actual site, and holds the potential to reduce the gap between reality and construction simulations.

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THERMAL PERFORMANCE OF MOSQUE ARCHITECTURAL FORMS AND ITS IMPACTS ON INDOOR TEMPERATURES AND THERMAL COMFORTS - Al-Sharjah as a case study[1]

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ABSTRACT: *Hundreds of mosques have been built to serve people in Sharjah city. A previous research published in 2007 has investigated the main mosque forms in the city of Sharjah, four forms were found: square, square with small additives in four directions, rectangle, and octagonal. Herein, in this study the forms are simplified to three forms instead of four for the similarity between the first two forms. The study investigates the effect of these forms on its thermal performance, occupants' thermal comfort, and indoor temperature. Three model scenarios representing the original three forms have been developed using the ECOTECT software. The locations of the buildings and its area and materials plus the internal heat gain were kept the same in the simulation models. From the investigation, results obtained showed a significant effect of mosque form and construction on its thermal performance, indoor temperature and occupants' thermal comfort. Therefore, It is recommended to revise the existing designing approach to consider best forms and construction details that consume less energy and achieve the comfort.*

KEYWORDS: *Mosque Design, Sharjah City, Thermal performance, Thermal Comfort, Indoor Temperature*

❖ INTRODUCTION

Mosque in Arabic called "masjid", which is a defined space of worship for followers of Islam, where all Muslims can meet together for prayers. Historically, the mosque worked as a center for information, education, and dispute settlement. The main spaces in mosque buildings are: prayer hall, dome and minaret, services area for toilets and ablution, Imam residence, and courtyard (not in all buildings). As mentioned earlier, hundreds of mosques have been built to serve people in Sharjah city. This number of mosques is in an increase as the government is giving a special attention to the religious buildings. Locally, many endeavors and studies had focused on sustainability issues; few of them discussed the environmental aspects of mosques. There have been several calls asking for proper use of passive design tools like shading devices, insulation, and natural ventilation in order to improve the thermal performance of indoor spaces.

Regionally, the topic is immensely active on the table and many researchers have investigated the performance of such buildings like (Asfour,2009), (Abideen, 1997), (Al-Najim and Al-Mofeez ,1999). Therefore, the authors have decided to investigate the effect of mosque forms and passive design on its thermal performance within the comfort limits.

According to a previous research published in few years ago (AWAD, 2007), four forms were found: square, square with small additives in four directions, rectangle, and octagon. It is noticed that these forms can be simplified to three forms instead of four for the similarity between the first two forms.

The impact of the passive design's elements on room temperature has been studied to improve indoor comfort. Herein, achieving environmentally friendly designs within the most modest means in a sound environment is urgently needed.

Three strategies namely: shading, ventilation, insulation for walls, roofs and floors in addition to a baseline case were conducted in the study in order to obtain effective solution for indoor environment. The modelling analyses would focus on summer rather than winter for its obvious problems of hight"Tempaerature and Heat".

This study aims to show the impact of passive tools on building thermal performance under hot climate regions and to investigate the effect of building forms on its thermal performance which would help future design to list its priorities, tools, and materials towards sustainability, and would assist decision makers set their priorities on passive tools and proper form within comfort limits

Herein, this study focuses on evaluating some common passive parameters such as shading devices, natural ventilation, and insulation on mosques.

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[1] Citation: Mushtaha, E. S. (2014). Thermal performance of mosque architectural forms and its impacts on indoor temperatures and thermal comforts – Al-Sharjah as a case study. In: N. Dawood and S.Alkass (Eds.), Proceedings of the 14th International Conference on Construction Applications of Virtual Reality, 16-18 November 2014, Sharjah, UAE.

OJECTIVES

The main objectives of this study are to investigate:
1. The impact of passive design on building thermal performance.
2. The effect of building forms on its thermal performance.
This would help designers and decision makers list their priorities, forms, and materials towards sustainability.

THE EFFECT OF MOSQUE FORM AND CONSTRUCTION ON THERMAL PERFORMANCE

Study Methodology

The selected research methodology here is using ECOTECT computer software to simulate the thermal performance. Using computer software enables studying various scenarios of building mass, geometry and materials, under specific climatic conditions.

Ecotect

Ecotect is one of the most common environmental software analysis and simulation packages, which is widely used both professionally as well as on research projects. Using a graphical interface, the building models are generated and materials, dimensions and building elements are specified. The finished model is then simulated with specific climatic conditions and numerical as well as visual results are obtained. Ecotect version 2011 was used during this research.

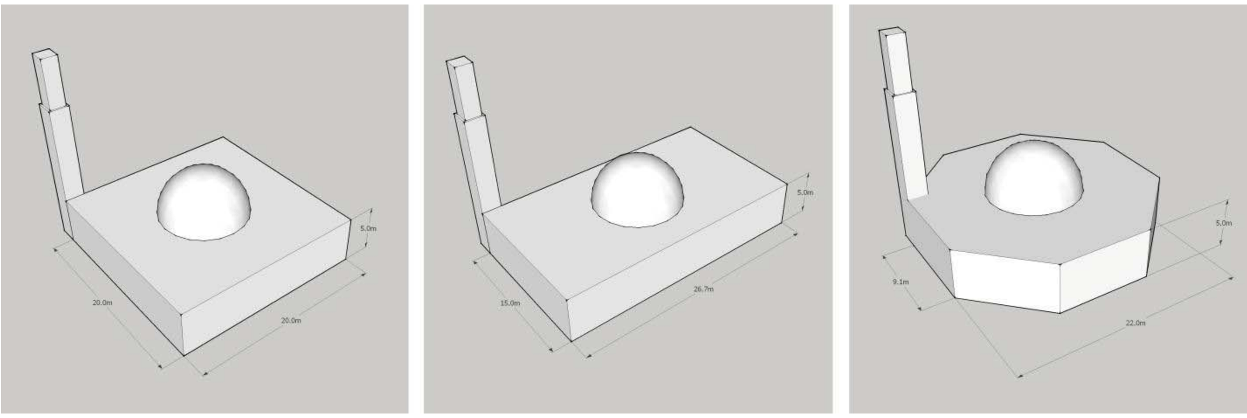
Climatic conditions

As the research is looking at mosques in the city of Sharjah, UAE. No specific climatic data file could be obtained at the time of this study for Al Sharjah city. However due to the close proximity of the city of Dubai, whith the borders of sharjah and Dubai merging together. The climatic data file for Dubai was used. 90% of the mosques in Sharjah lie within a 50km radius circle from Dubai.
Dubai and Sharjah have a hot and arid climate with mild warm winters (23^o average high temperatures) and extremely warm and humid summers (42^o average high temperatures). Accordingly internal thermal comfort is not a problem in winter compared to summer, and it was hence chosen to model the thermal performance inside the mosque at the worst possible scenario, which is the average hottest day of the year, which is the 19^{th} of August according to the Ecotect weather file.

Mosque occupation schedule

Ecotect allows setting up an occupation schedule for each zone in the model. This is beneficiary in the mosque scenario as the mosque occupation patterns varies greatly according to prayer times. The mosque simulated has a constant indoor area of $400m^2$, this allows for a peak occupation of 800 prayers (2 persons per square meter). From many sites observation, the following occupation schedule was used in this study:
1. 5% constant occupation of the prayer space
2. 20% occupation during daily prayers (5 prayers per day)
3. 100% occupation during the Friday prayer.

Selected Forms



From the literature, three main mosque forms where selected: The square mosque, the rectangular and the octagonal mosque. The form of such where simplified to the bare minimum relevant to this study. The areas of the mosques are kept constant at 400 m^2 and height at 5m. Hence the three variants have an equal internal volume and occupation capacity.

Study variations matrix

For each of the three cases selected, several variation where tested, representing the baseline (standard mosque construction and practice) as well as 5 other variations for passive design strategies suitable for the selected climate. These strategies include: Fabric insulation, Solar shading and natural ventilation. Also combining these strategies together has been studied, as per the following matrix:

		Square	Rectangle	Octagon
1	**Baseline**	**A1**	**B1**	**C1**
2	**Insulation**	**A2**	**B2**	**C2**
3	**Shading**	**A3**	**B3**	**C3**
4	**Insulation + Shading**	**A4**	**B4**	**C4**
5	**Ventilation**	**A5**	**B5**	**C5**
6	**Ins. + Shad. + Vent.**	**A6**	**B6**	**C6**

The different cases are explained below:

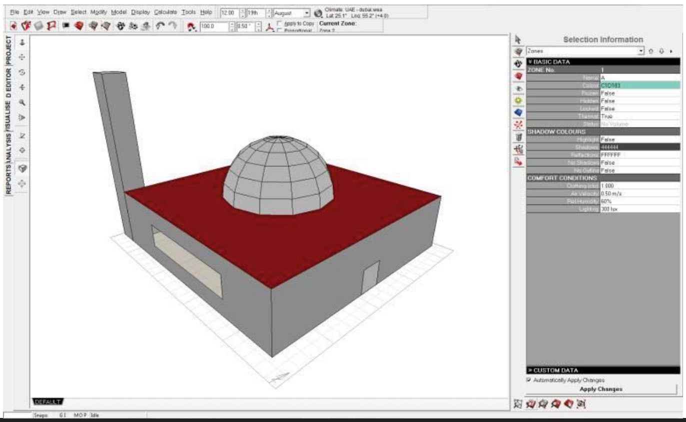
Baseline case

The baseline cases (A1, B1, C1) represent the standard practice for mosque buildings with the standard building materials.

Component	Material	U- Value	Admittance	Width
Wall	Concrete Block with Plaster	1.170	3.690	235mm
Windows	Single Glazed – Aluminum frame	6.00	6.00	6mm
Floor	Concrete Slab with Carpet	0.920	6.00	1,620mm
Roof	Clay Tiled	3.10	3.10	135mm

Insulation

Thermal insulation increases the resistance of the building materials to heat transfer, which mainly regulates the fabric heat gains and losses. This has a double effect, of reducing the heat gain from the outside during the peak temperature hours as well as preventing heat loss during night, which is an effect known as thermal lag
In these second cases (A2, B2, and C2) have been upgraded with insulation materials with much better U values, this included insulated walls, double glazed windows and an insulated green roof.



Component	Material	U- Value	Admittance	Width
Wall	Double Concrete Block with Polystyrene insulation	0.420	3.910	280mm
Windows	Double Glazed – Air gap – Aluminum frame	2.410	2.380	42mm
Floor	Concrete Slab with Carpet	0.920	6.00	1,620mm
Roof	Concrete roof – insulation – gravel and soil with grass	1.030	4.50	570mm

Shading

Solar shading blocks direct solar radiation from entering the building through glazed windows, such as physical vertical and horizontal shading devices. These horizontal louvers where designed to block the direct solar radiation on windows during the summer months (June to Aug) between the hours of 10:00am in the morning and 3:00pm in the afternoon.
Ecotect solar shading design wizard was used to accurately model the shading devices according to those parameters. This strategy is explored in cases (A3, B3, and C3)

Ventilation

For a mosque building, people go in and out very frequently, hence insuring a tight building is almost impossible. Some large mosques counter that by using double doors, however in this size of mosque a single door is used. The average air change rate for such has been set at 2 ach/hr. Natural ventilation as a passive strategy helps increase thermal comfort by increasing air change rate. Hence this strategy was explored by introducing natural ventilation within the mosque space at a rate of 10 air changes per hour. Explored in cases (A5, B5, C5)

Combining Strategies

Cases (A4, B4, and C4) explore combining insulation and natural ventilation strategies.
Cases (A6, B6, and C6) explore combining the three passive strategies: Insulation, Shading and Ventilation.

ANALYSIS
Case A
Description

Case A is a square Mosque with an area of 400 m^2, dimensions are 20 x20m. The mosque is oriented to point towards Qibla, 102^o degrees clockwise from North. This makes the facades almost north, east, south and west oriented respectively. The mosque space has a height of 5m. A door is placed on the opposite side of the Qibla for an entrance. The other three facades have windows equal to 20% of the façade area. Windows are all 2m in height with a sill of 1.5m

Thermal Performance Analysis – Internal temperatures

The above model with variations listed earlier was run on Ecotect and internal temperatures for the "Average hottest summer day" (19th of August), was extracted as follows:

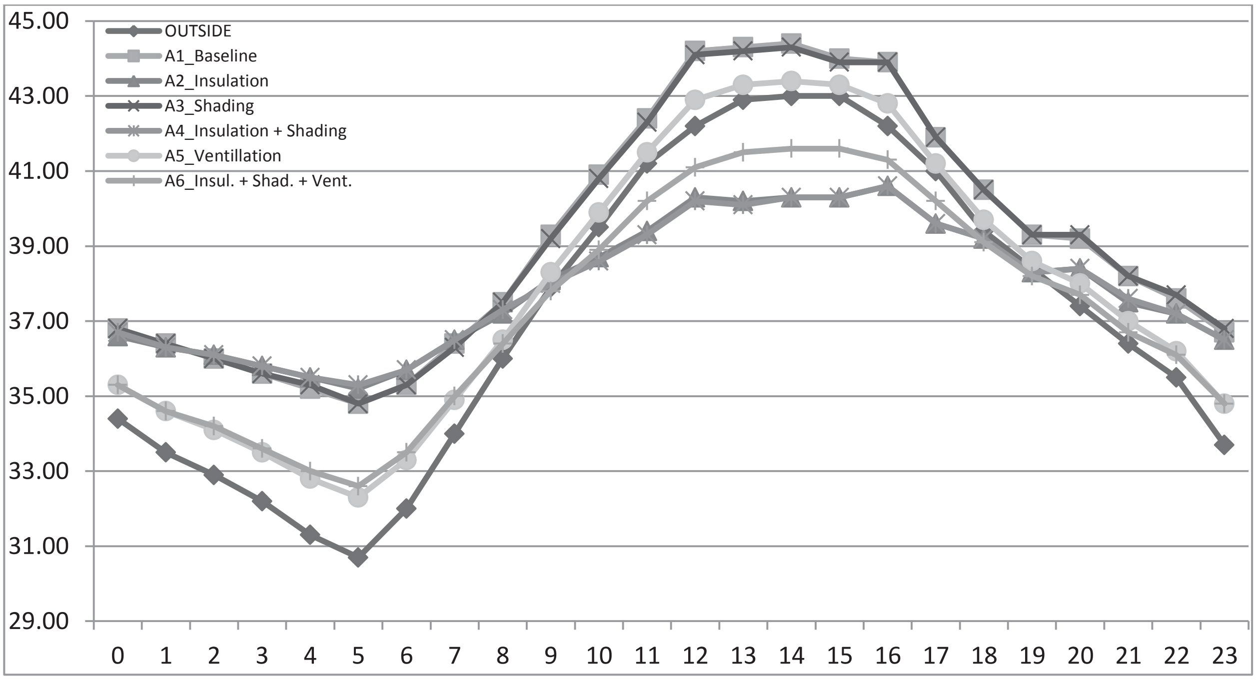


Figure 11 - Case A thermal performance

Case A1

This case considered the baseline; normal practice for mosque buildings uses the standard materials, with minimal insulation, 2 air changes per hour and high envelope leakage.
For the Baseline case B1, internal temperatures are around (4.7^o) above the outdoor temperatures during the lowest temperatures of the day at 5am and around (1.3^o) above the peak temperature at 2pm.

Case A2

In this case, highly insulated materials are used in walls, windows and roof. For case A2, the added insulation has greatly benefited the internal comfort, by regulating the temperatures. The temperatures at 5am are around (3.6^o) above the outdoor temperatures, however peak temperatures at 2pm drop by more than (2.7^o).

Case A3

In this case, shading devices are added to block the sun at peak temperature hours from 10:00am to 3:00pm. Almost no advantage was shown by shading alone in this case. Temperatures are almost similar to the baseline case with a drop of less than (0.1^o).

Case A4

Case A4 combines the insulation from case A2 with the shading devices from case A3.
Again showing almost similar results to the case A2 (insulation alone). With minimal advantage gained from shading the windows in this scenario. Less than (0.1^o) difference.

Case A5

This case explores the effect of natural ventilation, by increasing the air change rate 5x times the standard.
Ventilation in such a climate shows approx. (1.5^o) increase I indoor temperatures above the outdoor temperatures during the coldest time of the day at 5am and around (0.4^o) above the peak temperature at 2pm.

Case A6

This case combines all the 3 strategies tried in the previous options
For case A6, internal temperatures are approx. (4.6^o) above the outdoor temperatures during the lowest temperatures of the day at 5am and around (2.7^o) below the peak temperature at 2pm.
The average temperatures for the six cases are as follows:

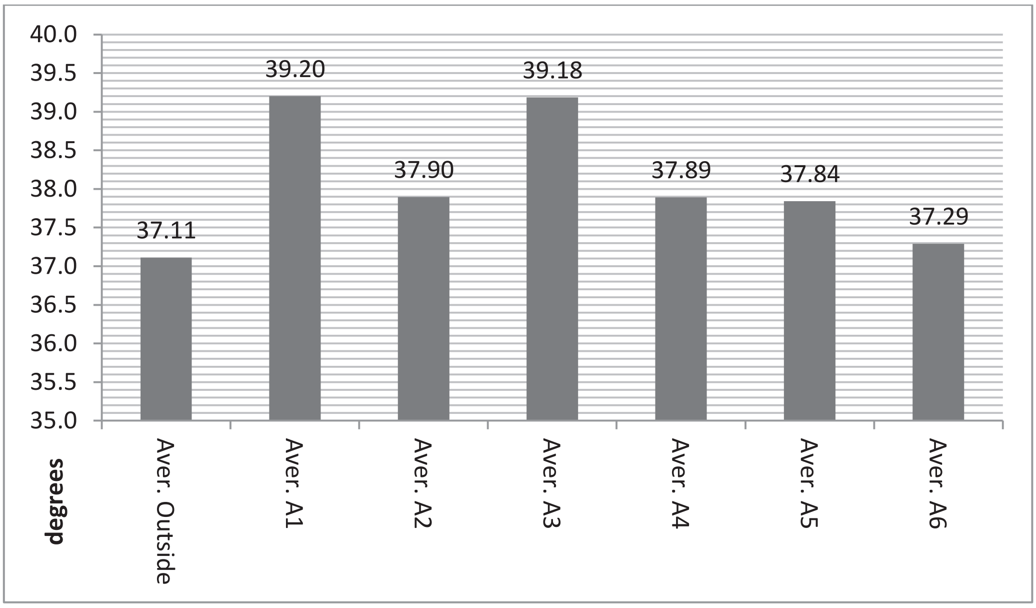
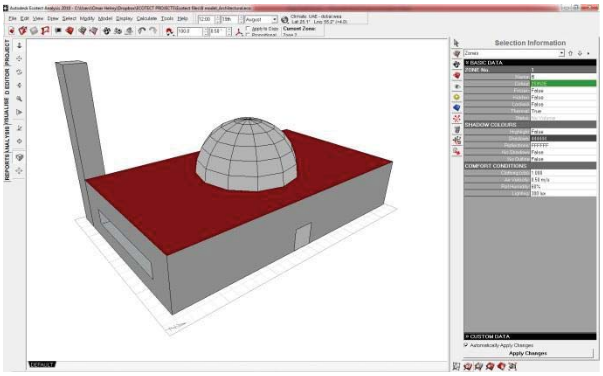


Figure 12 - Average Temperatures For Case A

A study of the average temperatures for the 6 scenarios in comparison to the ambient temperatures reveal that although casesA6, A5 and A4 are performing better than the other cases, average temperatures within the space cannot be dropped to comfortable levels with passive strategies alone.

Case B
Description

Case B is a rectangular Mosque with an area of 400 m^2, dimensions are 15 x 26.6m. As per the preferred Islamic rule, the longest side is towards Qibla. Similar to case A,the mosque s rotated 102^o clock wise towards the qibla. This makes the facades almost north, east, south and west oriented respectively.The mosque space has a height of 5m.A door is placed on the opposite side of the Qibla for an entrance. The other three facades have windows equal to 20% of the façade area. Windows are all 2m in height with a sill of 1.5m



THERMAL PERFORMANCE ANALYSIS – INTERNAL TEMPERATURES

The above model with variations listed earlier was run on Ecotect and internal temperatures for the "Average hottest summer day" was extracted as follows:

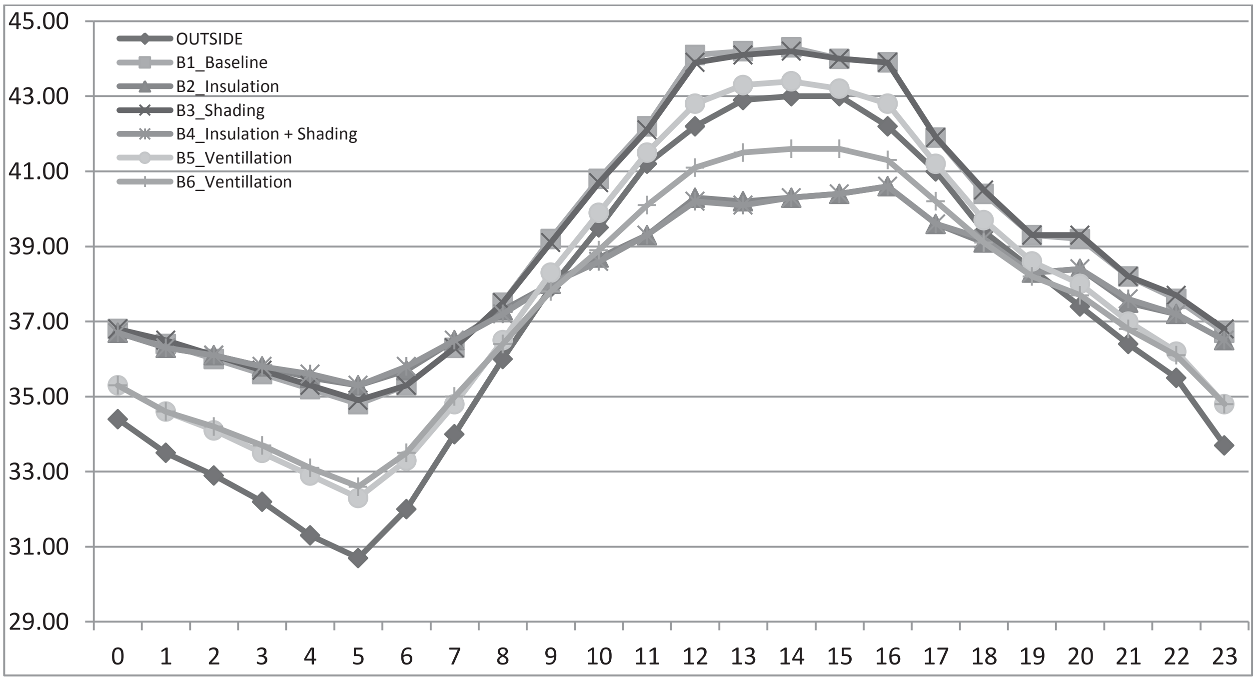


Figure 3 - Case B Thermal Performance

Case B1

This case considered the baseline; normal practice for mosque buildings uses the standard materials, with minimal insulation, 2 air changes per hour and high envelope leakage.

For the Baseline case B1, internal temperatures are around (4^o) above the outdoor temperatures during the lowest temperatures of the day at 5am and around (1.5^o) above the peak temperature at 2pm.

Case B2

In this case, highly insulated materials are used in walls, windows and roof. For case B2, the added insulation has greatly benefited the internal comfort, by regulating the temperatures. The temperatures at 5am are around (4^o) above the outdoor temperatures, however peak temperatures at 2pm drop by more than (4^o).

Case B3

In this case, shading devices are added to block the sun at peak temperature hours from 10:00am to 3:00pm. For case B3, Almost no advantage shown by shading alone in this case. Temperatures are almost similar to the baseline case

Case B4

Case B4 combines the insulation from case B2 with the shading devices from case B3. For case B4, again showing almost similar results to the case B2 (insulation alone). With minimal advantage gained from shading the windows in this scenario. Less than (0.1^o) difference.

Case B5

This case explores the effect of natural ventilation, by increasing the air change rate 5x times the standard. For case B5, ventilation in such a climate shows approx. (2^o) above the outdoor temperatures during the lowest temperatures of the day at 5am and around (0.5^o) above the peak temperature at 2pm.

Case B6

This case combines all the 3 strategies tried in the previous options
For case B6, internal temperatures are approx. (2.1^o) above the outdoor temperatures during the lowest temperatures of the day at 5am and around (2.4) below the peak temperature at 2pm.
The average daily temperatures for the six cases are as follows:

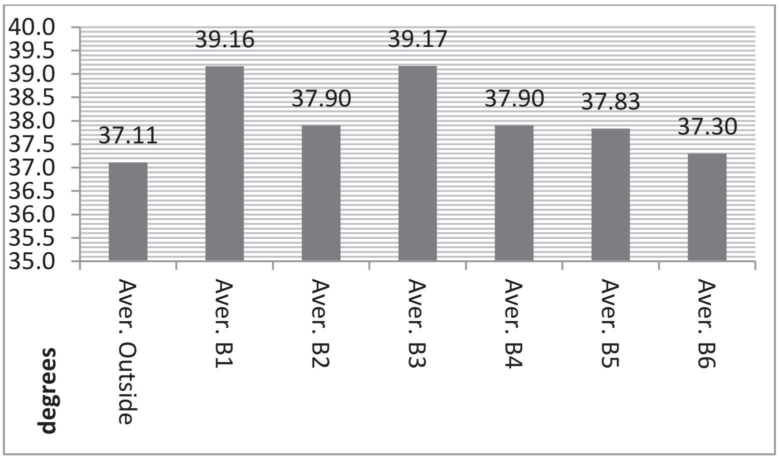


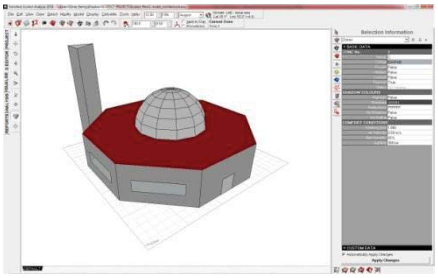
Figure 4 - Average Temperatures for case B

A study of the average temperatures for the 6 scenarios in comparison to the ambient temperatures reveal that though case B6, B5 and B2 are performing better than the other cases, average temperatures within the space cannot be dropped to comfortable levels with passive strategies alone.

Case C
Description

Case C is anoctagonalmosque with an area of 400 m^2, with each side measuring 9.1 m. The mosque space has a height of 5m.A door is placed on the opposite side of the Qibla for an entrance. The other 7 facades have windows equal to 20% of the façade area. Windows are all 2m in height with a sill of 1.5m.

THERMAL PERFORMANCE ANALYSIS – INTERNAL TEMPERATURES



The above model with variations listed earlier was run on Ecotect and internal temperatures for the "Average hottest summer day" was extracted as follows:

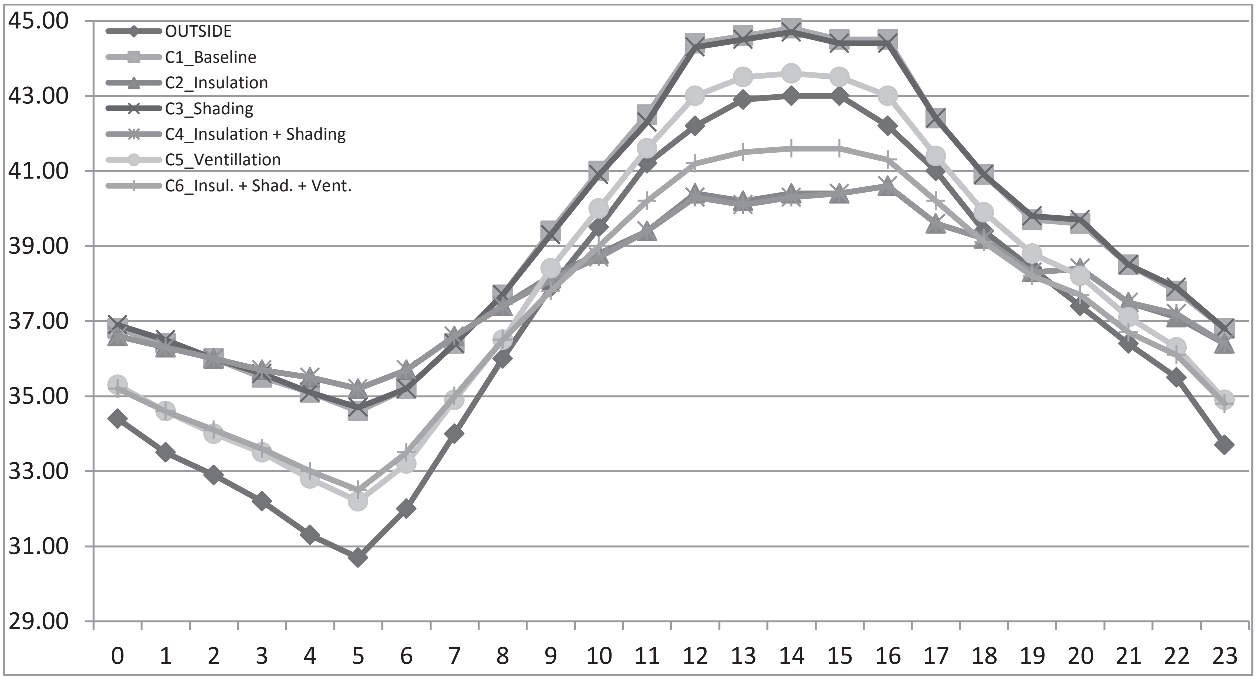


Figure 5 - Case C Thermal Performance

Case C1

This case considered the baseline; normal practice for mosque buildings uses the standard materials, with minimal insulation, 2 air changes per hour and high envelope leakage.
For the Baseline case C1, internal temperatures are around (4^o) above the outdoor temperatures during the lowest temperatures of the day at 5am and around (1.9^o) above the peak temperature at 2pm.

Case C2

In this case, highly insulated materials are used in walls, windows and roof.

For case C2, the added insulation has greatly benefited the internal comfort, by regulating the temperatures. The temperatures at 5am are around (4.2^o) above the outdoor temperatures, however peak temperatures at 2pm drop by approx. (4.8^o).

Case C3

In this case, shading devices are added to block the sun at peak temperature hours from 10:00am to 3:00pm.
For case C3, shading shows a drop of less than (0.1^o) compared to the baseline case C1.

Case C4

Case C4 combines the insulation from case C2 with the shading devices from case C3.
For case C4, again showing almost similar results to the case C2 (insulation alone). With minimal advantage gained from shading the windows in this scenario. Less than (0.1^o) difference.

Case C5

This case explores the effect of natural ventilation, by increasing the air change rate 5x times the standard.
For case C5, ventilation in such a climate shows approx. (1.8^o) above the outdoor temperatures during the lowest temperatures of the day at 5am and around (0.6^o) above the peak temperature at 2pm.

Case C6

This case combines all the 3 strategies tried in the previous options
For case C6, internal temperatures are approx. (1.8^o) above the outdoor temperatures during the lowest temperatures of the day at 5am and around (1.4) below the peak temperature at 2pm.
The average daily temperatures for the six cases are as follows:

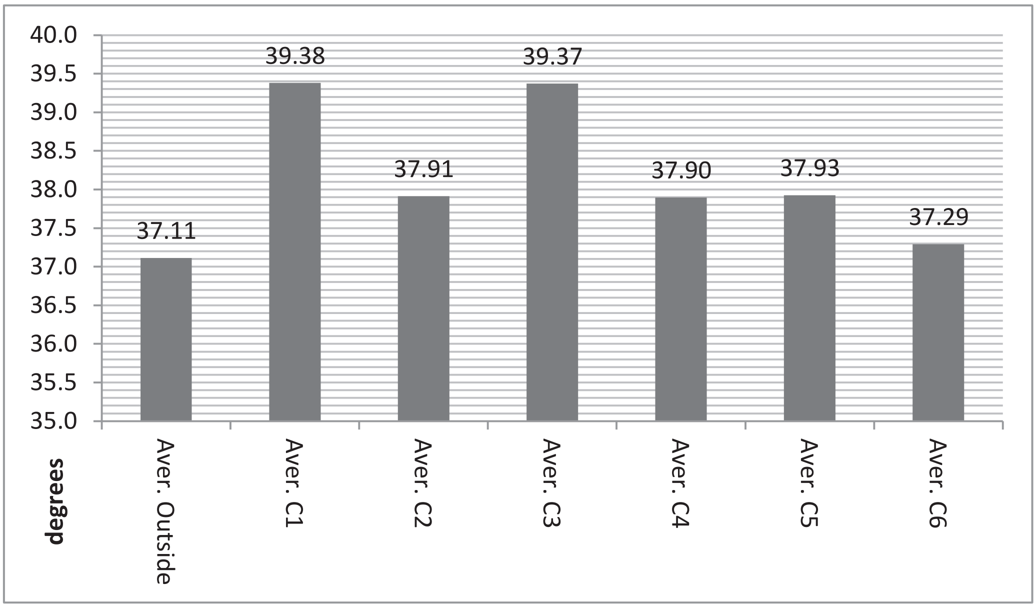


FIGURE 6 - AVERAGE TEMPERATURES FOR CASE C

A study of the average temperatures for the 6 scenarios in comparison to the ambient temperatures reveal that though case C6, C4 and C2 are performing better than the other cases, average temperatures within the space cannot be dropped to comfortable levels with passive strategies alone.

Comparing the three mosque forms a, b and c

Comparison of the three cases

The previous study has compared the performance for the variants (cases) of the three different mosque forms: A, B and C. Here we attempt to compare the best case for each form to establish the best performing geometry so far. Hence the temperature schemes for the cases: A6, B6 and C6 are compared and the difference in temperatures for each scheme against the ambient where plotted as follows:

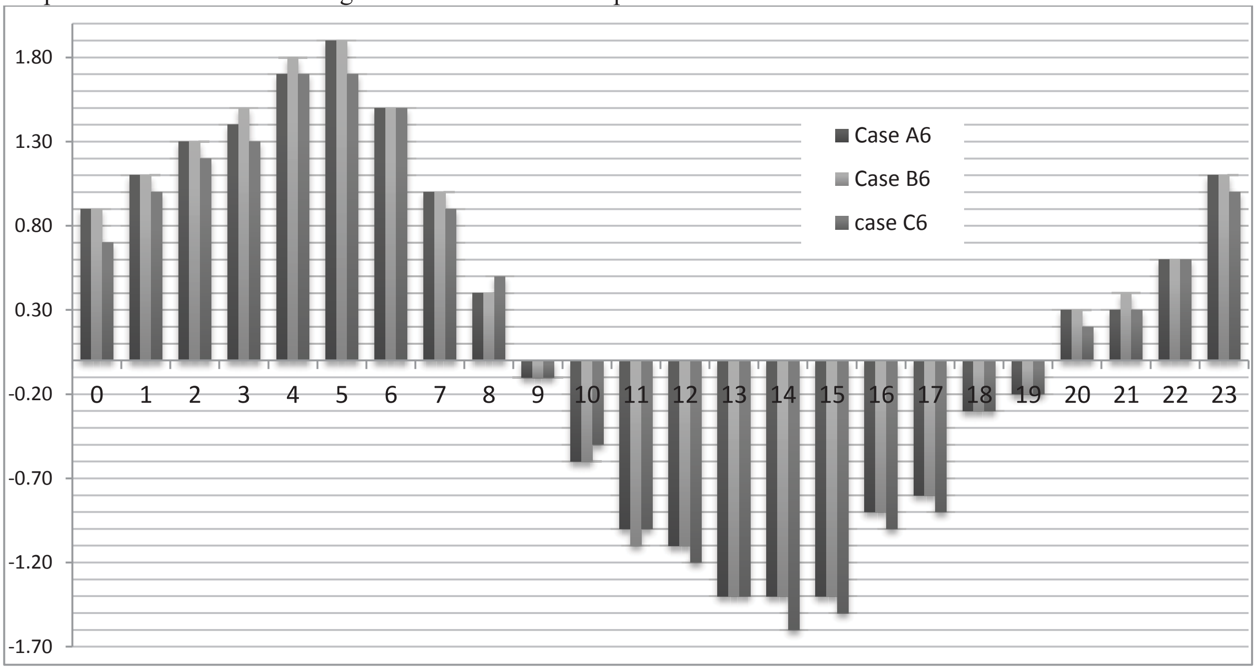


Figure 7 - Temperature variation for cases a, b and c

The comparison shows the octagonal mosque (Case C6) performing better than the other options in regulating the internal temperatures. Achieving the lowest average temperatures throughout the average warmest day. However as earlier recorded, none of the three cases with three variations, where able to drop the average indoor temperatures beyond the average outdoor temperatures. Generally indoor thermal comfort is not possible using passive strategies alone.

Study of the savings in the AC power load

Hence, as is the common practice in the region of study, active air conditioning systems are required to achieve thermal comfort in summer. However based on the simulations done, passive strategies where able to drop the indoor temperatures inside the mosque, by an average of (2.1^{o}) during the warmest summer day. The study was extended to study the savings in AC power load that can be achieved using such passive strategies compared to baseline case. Similar to the previous study, Ecotect software was used to calculate the AC power load during the full year for Cases (C1) and (C6), representing the best performing passive scenario, compared to its baseline. A hybrid air-conditioning system was assumed, with 95% efficiency, with a lower band thermostat range of (18^{o}) and an upper band of (26^{o}). This system operates only when the temperatures fall beyond the thresholds, and remains off otherwise.

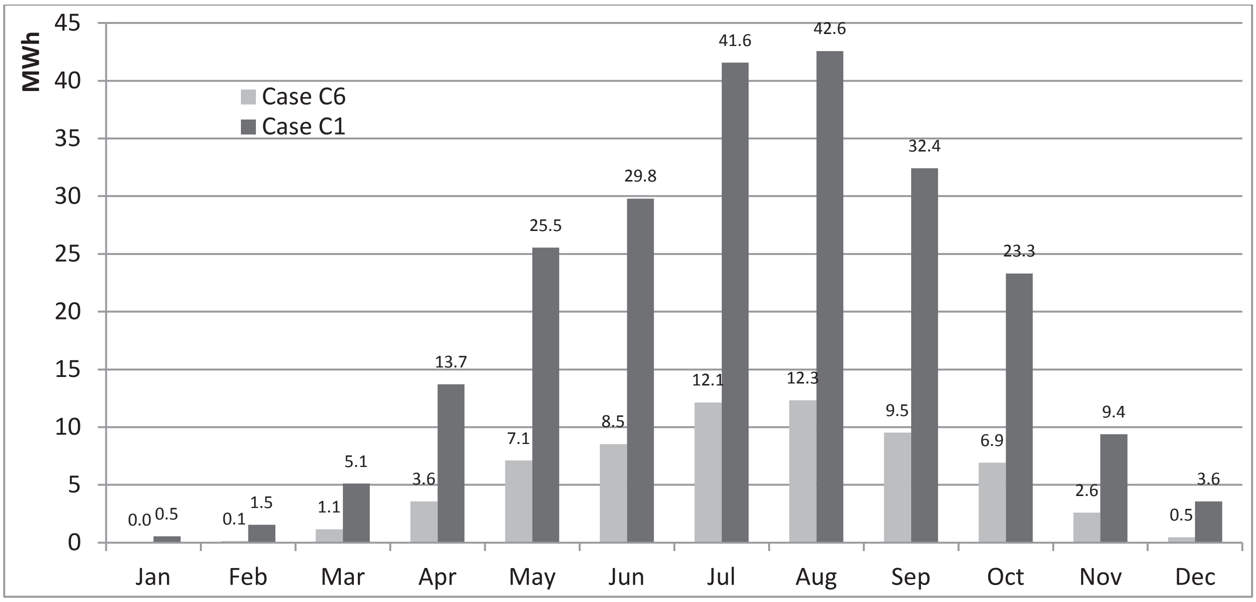


Figure 8 - AC cooling load comparison for the baseline case C1 and best passive strategies C6

The figure above is showing a considerable savings in AC cooling load, between the passively designed Case C6 compared to the baseline case C1. The total yearly cooling load calculated by Ecotect dropped from 229 MWh per year for the C1, to 64 MWh per year for case C6. The maximum savings occur on winter months (December to February) with the cooling load almost eliminated (13% to 2% of the original load), while savings in summer though less (approx. 71% from June to August) are still considerable. The average savings are 77% of the original load.

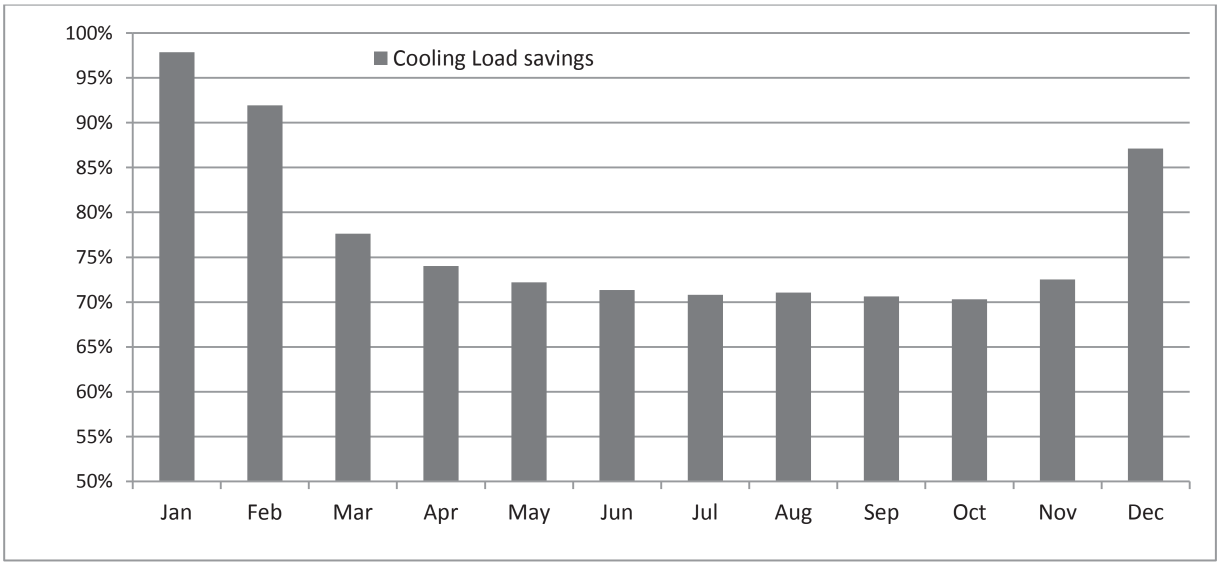


Figure 13 - Savings in cooling load for case C6 compared to C1

The simulation also shows a drop in the peak cooling load from 123,815 W at 14:00 on the 19^{th} of August in case C1, to 40,209W at 12:00 on the 31^{st} of August in case C6. This means a 67.5% reduction in the cooling load, which allows designing a much smaller HVAC system to handle such a load compared to the baseline case, further contributing to lowering the initial cost, as well as running a more efficient system with optimized load.

SUMMARY AND CONCLUSIONS

SUMMARY

EFFECT OF MOSQUE GEOMETRY

The simulation done, showed that even though there is an effect of the mosque geometry on its performance. This effect is a negligible impact compared to the other factors, this mainly relates to the geographic location of the study in the UAE, where the sun angles during summer are so high, that the orientation of the facades has almost no effect.

Never the less, the Octagonal mosque performed better than the other geometries, this is due to the fact that it has the smallest surface area versus the internal volume, with the square mosque having a bigger surface area and the rectangle having the biggest surface area. The small surface area in such a climate reduces the fabric gains through the walls and roofs, resulting in lower internal temperatures.

PASSIVE STRATEGIES

Several passive strategies where simulated, including Insulation, Solar Shading and Ventilation, as well as two combination. The simulations showed the following:

- Thermal insulation showed the most profound effect on reducing the internal temperatures during the peak hours averaging (2.7^{o} below ambient outside temperatures) and (4.2^{o} below baseline case)
- Solar shading has a lesser effect on reducing the internal temperatures compared to the ambient. (1.7^{o} above ambient outside temperatures) and (0.1^{o} below baseline case). This is the result of the sun angles in summer being extremely vertical, reducing the efficiency of the shading louvers
- Natural ventilation had a very limited effect, mainly due to the high ambient outside temperatures. Showing (0.6^{o} above ambient outside temperatures) and (0.9^{o} below baseline case)
- Combining the three strategies proved to be the most effective over-all managing to regulate the indoor temperatures to approx. (0.2^{o} above the ambient outdoor temperatures)
- However, none of the passive strategies nor their combinations was able to drop the indoor temperatures to comfortable levels. This is mainly due the very high outdoor temperatures during summer and the high heat gain due to occupancy inside the mosque.

ACTIVE STRATEGIES AND SAVING ENERGY

It was clear from the analysis done that due to the harsh summer climate in the UAE; it's not possible to achieve thermal comfort in mosques with passive strategies alone. The combination of very high summer temperatures almost all day, the high relative humidity as well as the high internal heat gain from the large number of prayers, makes the use of active strategies to cool the space to reasonable temperatures a necessity.

However from the previous analysis, it was clear that passive design can help reduce the AC cooling load, by dropping the internal temperatures as well as reduce the external heat gain.

To measure the efficiency of such a scenario, a comparative study was done to calculate the monthly cooling load of the baseline case C1 against the best passive scenario C6.

Results showed a huge savings in the cooling load throughout the year, a reduction that reaches almost 97% during January and averages around 71% during summer. The passive strategies in C6 have also reduced the peak cooling load from 123,815 W to 40,209W, a 67.5% savings.

CONCLUSION

The results shown in this study can be summarized in the following points:

- Mosque shapes with the minimum surface area achieve better performance in the Sharjah/Dubai climate, and reducing the external heat gain.
- Passive design strategies can help reduce the external heat gain as well as regulate the internal temperatures. However are not able to achieve thermal comfort conditions.
- Combining passive and active strategies significantly reduces the energy use for cooling the mosque space, as well as reducing the size of the HVAC units used.

FUTURE STUDIES

A number of other points can be explored in future studies relating to passive mosque design that have not been covered here:

- ❖ Combining renewable energy systems, like PVs on the mosque roof, to generate energy as well as reduce the solar heat gain by blocking the sun from reaching the roof surface.
- ❖ Using hybrid cooling systems like ground cooling to further optimize the active cooling.
- ❖ Exploring more innovative mosque building geometries like semi-spherical shapes or semi-buried buildings.

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MODELING SAFE LOCATION DETECTION FOR TEMPORARY SETTLEMENTS OF AFFECTED RESIDENTS IN CASE OF DAM FAILURE[1]

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ABSTRACT: This paper presents a model for site selection in order to provide temporary accommodation for local residence in case of any failure of hydraulic structures in the region. In this paper a decision making framework has been developed considering four main site selection factors: locational attributes, distance from the high risk area, access to the safe places and being adjacent with necessary land uses. In order to increase the reliability of the decision considering updating all new information, an algorithm called FRSS is developed that utilizes and integrates HEC-RAS, GIS and Experts Choice software. The model was applied to Zayanderoud river dam in the central part of Iran. The risk analysis as the requirement of the framework resulted in six hundred and thirty-two acres from the case study area as three hundred and fifty-six acres from them equal to 50% have a high degree of risk. According to FRSS system, about 50% of the area is in the low risk zone and it can be used for safe temporary sheltering.

KEYWORDS*:* *Modelling, Site Selection; Hydraulic Structure; Temporary Shelter, GIS, Visualization.*

❖ BACKGROUND

Reviewing of research projects about dam failures shows much consideration about its technical aspects and its effects on regional ecosystem, but there is less attention to dam failure’s effects on downstream settlements and the necessity of modeling and planning the resettlement of affected people. Swege et al. (2010) showed how to determine the flood risk areas and identify the safe areas with hydraulic modeling using GIS and HEC-RAS modeling. Another research which presents a method to site selection with regards to passive defense with GIS has discussed about effective locality alternatives in site selection resettles of passive defense view (Kheir abadi, Setare, & Tavakoli nejad, 2010).
The primary purpose of this paper is to provide a model for site selection temporary accommodation against failure of hydraulic structures. The objectives required to achieve this primary purpose are the following: (1) identifying the sites which are endanger of probable flood caused by failure of Zayandehroud dam; (2) determining the safe points near the flood area; (3) recognizing and determining the EMS points; (4) determining the escape route alternatives among the existing roads to transport the people from danger area to the safe areas; and (5) decreasing the vulnerable people who are habituated near the river path.

DATA AND METHODS

Data needed for this modelling attempt consists of geographical data such as topographical counter maps and also demographical data such as population, households and etc. This data with the other technical specifications related to the dam and the river path will analyzed with the use HEC-RAS tools. Therewith flood geographical specifications with population data which are needed to making FRSS model will be modeling in geographical

[1] Citation: Sargolzie, S., Sepasgoza, S., Irajifar, L. & Al Jassmi, H. (2014). Modeling safe location detection for temporary settlements of affected residents in case of dam failure. In: N. Dawood and S. Alkass (Eds.), Proceedings of the 14th International Conference on Construction Applications of Virtual Reality, 16-18 November 2014, Sharjah, UAE.

information system (GIS) in the third stage. And finally in the last stage, using the decision making method, AHP, and Expert Choice tools the selected areas in GIS will prioritize.

a) 2D data analysis; for site selection temporary accommodation against failure of hydraulic structures 2D data of the case study are needed for the first stage. These data, the elevation points, was extracted from DGN files that are produced by survey organization. In AutoCAD file, the elevation points were converted to topography contours with terrain model explorer and terrain creates contours tools.

b) HEC-RAS modeling; for dam failure analysis in the second stage, the contours created in the previous stage and some characteristics such as the size of the opening in dam and flood hydrograph output are needed. These data will be used in hydraulic modeling in HEC-RAS analysis. To this stage of analyze, transverse sections of the river was created, then a complete model of the river was produced, and finally roughness coefficients were applied. Some technical characterize of dam which are needed in the analytical modeling are the kind of dam, the height of dam, the length of dam crest, the width of dam in foundation and crest. The outputs of this stage are flood depth layer and boundary flood layer. The flood boundary layer will be used in the next stage to identify the risk area.

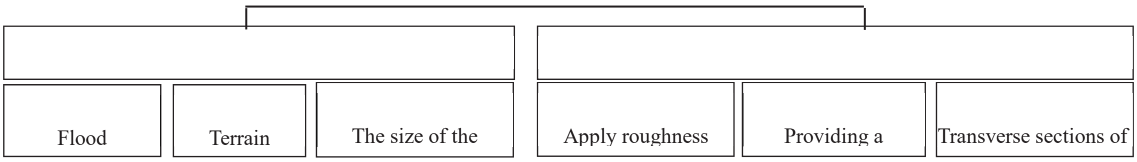

Figure 1: Step2 in FRSS modelling; HEC-RAS modelling

c) GIS modeling; to create the model at first special layers such as land uses, access network, river network, depth and boundary of flood and population data like family dimension, density, age ratio and gender in the case study scale should be integrated. For site selection analysis there are some tools such as extract, clip, calculate area and select by attribute in Arc map. GIS model will propose some alternatives that have the best conditions to be the safest areas.

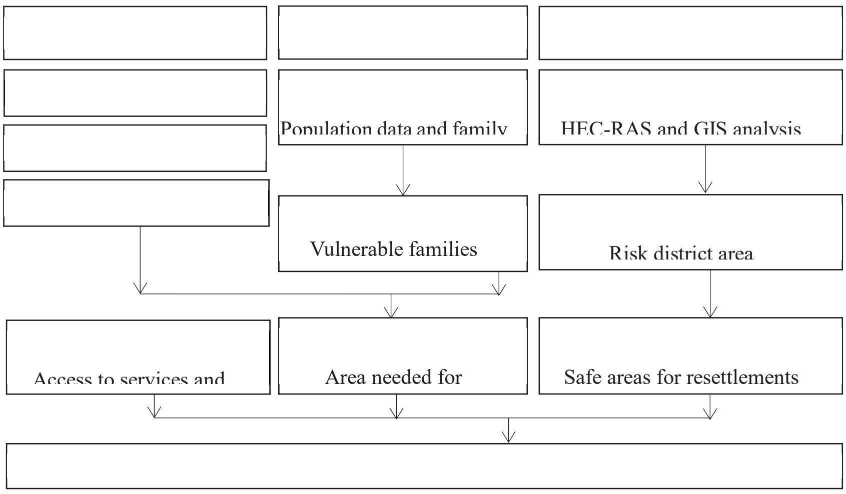

Figure 2: Step3 in FRSS modelling; HEC-RAS modelling

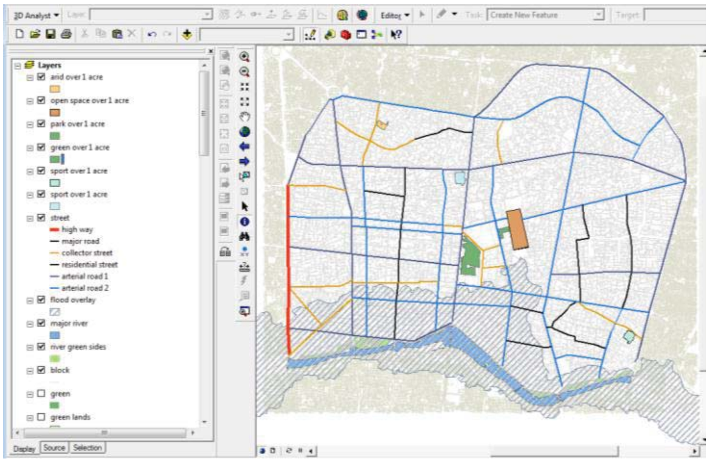

Figure 3: The selected site areas based on their consistency with two sets of criteria

For choosing the safe sites for temporary accommodation it's essential to divide criteria into two main groups including basic functional criteria and prioritization criteria:

1. First set of criteria includes: Being out of flood boundary, having the acceptable area and enjoying of suitable land uses which are as rejected criteria and will distinct all alternatives that have at least operation property. For interfering the first group of sub-criteria selected by attribute command will be used in Arc map software. Therefor among the all alternatives which are in the safe area just the alternatives which are out of flood boundary, have the minimum area (1 acre) and no-vital land uses will be remained (Pourmohamadi, 2006).
   After interfering sub-criteria, among 28 sites which exist in the case study, 6 sites are the most adaptive ones and can be choose as temporary accommodation. The locations of these sites are shown in map 9.
2. Second set of criteria estimates the efficiency of alternatives. Thus the alternative which meets these criteria has the most precedency. This group of criteria is called as adaptability criteria. One of the most important issues before crisis is selecting the suitable site for temporary accommodation because a bad site can make the conditions as worst. Whereas this paper is to making a multi variation site selection model, it should be consist of some criteria that make the best condition for any site. So four proposed criteria which are used in this paper are introduced; nature of sites and locations, distance from the dangerous area, accessible to the safe sites and being adjacent with necessary land uses. Each of these criteria has some sub-criteria which are shown in figure 5.

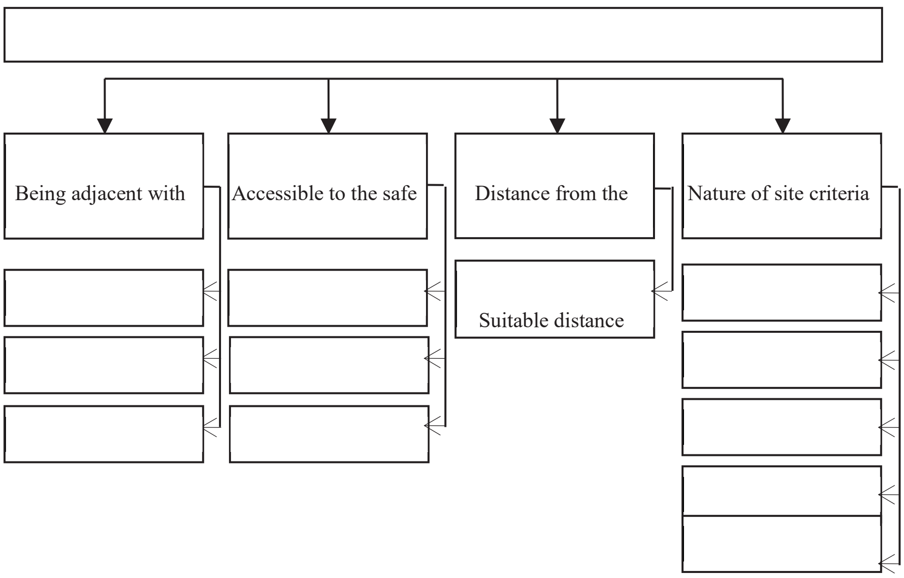

Figure 4: criteria and sub-criteria for resettlement site selection

d) AHP modeling; in the last stage, for deciding on which alternative is the best one among the others, the AHP modeling has been utilized. For decision making some criteria are introduced. These criteria are include; nature of sites and locations, distance from the high risk area, accessible to the safe sites and being adjacent with necessary land uses. The alternatives will analyzed with these criteria in Expert Choice software. The output of this stage is prioritized alternatives.
The steps of AHP for catching this object are; formation hierarchical structure, couple comparison and determining the value of criteria and sub-criteria based on the main purpose, couple comparison and determining the value of alternatives based on sub-criteria, prioritizing the alternatives and finally adaptability test.

Modelling the hierarchical structure

Modelling the hierarchy is the most important step of AHP. This structure is shown in figure 5. The hierarchy presented in this paper consists of four elements:
Goal: site selection temporary accommodation against the flood caused by dam failure.
Criteria: Nature of site, Distance from the dangerous area, Accessible to the safe sites and Being adjacent with necessary land uses.
Sub-criteria: such as Flexibility, public ownership, capacity, suitable land use, Suitable skeleton, EMS stations, Fair stations …

Pairwise comparison and determining the value of criteria and sub-criteria based on the main purpose

After forming the hierarchical structure for determining the relative value of criteria and sub-criteria the couple comparison uses the coordination matrix. These matrixes import some couple comparisons as arrival data and export the values. This step is done in Expert choice software. But because there are 16 couple comparison tables in this AHP modeling, here just one is shown as an example in figure 7. Surely in this step the viewpoints of experts are import in the value matrix.

Pairwise comparison and determining the value of alternatives based on sub-criteria
After determining the value of criteria and sub-criteria relate to each other, in this stage the values are determining to the alternatives relate to the sub-criteria. In this stage the viewpoints of experts will be use d too.

Prioritizing the alternatives
For determining the final value of each alternative and prioritizing them, it's essential to multiply the value of each criterion into its sub-criterion and its result must be multiplied into the value of alternative relate to the same sub-criterion. Finally the sums of these results are known as the final value of each alternative and make prioritized them. So any alternative which has the maximum value will be in top. And similarly the other alternatives will be arranged based their final values.

Consistency test

For scrutiny of judgeship and being sure of prioritizing of alternatives, Adaptability test is done for all stages. If AHP indicator be less than 0/1, the judgments are adaptive (Pourmohamadi, 2006). In Expert choice software the disagreeable rate is done by software.

RESULTS

Aforementioned procedure was applied to Zayanderoud dam area. The high risk flood areas were identified best on the first stage analysis. In the second phase, the identified alternatives were further been assessed based on two sets of criteria: Basic functional criteria and prioritization criteria. Diagram below shows the prioritization criteria and sub criteria. After interfering sub-criteria, among 28 sites which exist in the case study, 6 sites are the most adaptive ones and can be choose as temporary accommodation.

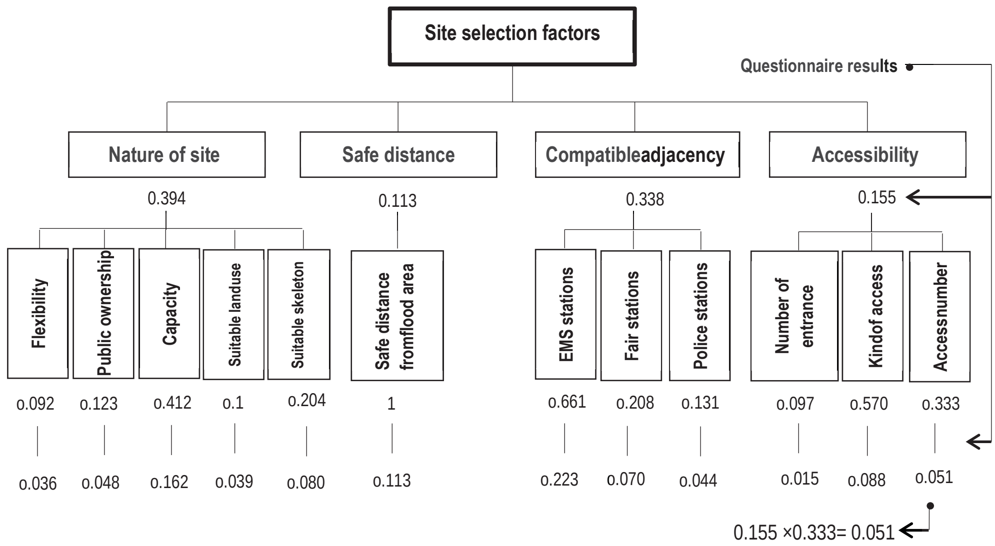

Figure 3: Questionnaire result of multiply the value of each criterion into its sub-criterion

For calculating the final value of each alternative, the values of alternative based on each sub-criterion, sub-criteria based on criteria and criteria based on the goal should be multiplied to each other. And finally the sum of resulted numbers from this multiplying will be the final value of each alternative. For calculating the

For example: Aflexibility= 0.035 × 0.092 ×0.394= 0.0012

Apublic ownership= 0.26 × 0.123 × 0.394 = 0.0126

Avalue= Aflexibility + Apublic ownership + .+ . +…..

As the AHP result the calculated values for each alternative will prioritized them which are shown in table 1.

Table 1: prioritized alternatives

Rank of alternatives	label	Name	Final value
1	C	Takhti stadium	0.221
2	B	Shahid rajaei park	0.195
3	F	Naghsh jahan square	0.189
4	D	Shahid Nasr stadium	0.142
5	A	Art garden	0.133
6	E	Arid lot	0.117

As previously mentioned, the alternatives prioritization was carried out to evaluate the consistency of alternatives to the second group of criteria. However the crisis management team can choose the best one for temporary settlement t or even (s)he can choose some or all of them together based on the number of affected people.

CONCLUSION

The main purpose of this paper was to preserve the people who live in downstream areas of dams. Despite attention in design and performance of dams, there are many technical risks. Also there are some potential such as earthquakes, and attacks that make necessary the analyzing of downstream areas. As it was mentioned before, the primary purpose of this paper is to providing a model for site selection temporary accommodation against failure of hydraulic structures. The paper presented a model for site selection temporary accommodation. The model is verified by using the data from 2D data analysis tools, Arc map, HEC-RAS and SPSS soft wares. The result of implementation of the model in 1 and 3 regions of Isfahan area shows that there are just 6 sites that are adapted with the first criteria and can be used as a safe site to resettle the vulnerable people and finally these were prioritized according to the second set of criteria which show the Degree of compatibility for being a suitable site to residence the people. Hence the flood areas plan which is the most important criteria in FRSS model give the worthwhile data about depth and boundary of flood areas to the managers and planners. On the other hand, site selection for accommodation against the flood caused by dam failure is the requisite for any crisis management plan in urban and rural settlements in downstream areas. Paying attention to this problem is too important because of many settlements which are located in risk area. In this paper the mentioned soft wares in FRSS model are used to site selection temporary accommodation against the flood caused by Zayanderoud Dam in 1 and 3 districts in Isfahan city in Iran. The result of this model will be the sites which have the most adaption with determined criteria and so on will have the most efficiency for temporary habitation in case of floods. This model is created for the first time. FRSS has anticipated the criteria and sub-criteria and it will help the crisis managers to be more able and caused to decrease the victims.

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VIRTUAL REALITY IN THE AEC INDUSTRY: A LITERATURE REVIEW[1]

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ABSTRACT: *In recent years, the application of Virtual Reality technologies in the Architecture, Engineering, and Construction industry has tremendously increased. However, these virtual technologies are still developing and further investigation in this research domain is essential. This article provides an extended foundation for future research by presenting a review of virtual reality technology. The review is based on articles found within four well-known journals in the AEC industry for the period 2000 to 2012 inclusive: the Journal of Automation in Construction, the Journal of Information Technology in Construction, the ASCE Journal of Computing in Civil Engineering, and the ASCE Journal of Construction Engineering and Management. The review further narrows the literature within these journals by considering only those 259 articles found through a key word search for "virtual reality." The selected journal articles are classified in different dimensions e.g., improvement focus, organization type, industry type, project phase, target audience, stage of technology maturity, technology role, and technology type. The number of articles found to match each of these dimensions is used to identify emerging trends in the literature as well as to synthesize the current state-of-the-art of virtual reality research in the AEC industry. In summary, the VR literature has increasingly focused on technology production and applications and prominent technology roles such as visualization and simulation in the construction and design phases of the AEC projects; in parallel, the literature addresses issues faced by not-on-site audiences such as design team, and on-site audiences such as project managers in building/commercial projects.*

KEYWORDS: *Virtual reality, AEC industry, Construction management, Literature review*

❖ INTRODUCTION

The construction industry, due to its nature, continuously faces with major challenges. The rapid increase in globalization makes the construction industry dependent on Information and Communication Technologies (ICT) which address complications and difficulties that arise in a global environment. Virtual reality technologies with a wide range of capabilities in information management, simulation and visualization, communication and collaboration, can significantly meet construction industry needs in this arena.

Virtual Reality (VR) is defined as an interactive computer generated environment with three-dimensional objects and locations that can simulate both planned/designed models and real world scenes. Virtual reality technology greatly benefits AEC industry in terms of providing greater site safety, enabling construction professionals to test alternative construction methods, allowing more accurate sequencing of operations, and presenting a novel way of collaboration and communication between designers, suppliers and contractors (Dawood 2009). These beneficial applications demonstrate the potential of this technology for future use in this domain.

This paper presents a literature review of virtual reality technologies in the AEC industry up to and including the year 2012. The aims of this review are (1) to synthesize the current state-of-the-art of virtual reality technologies for AEC construction projects, and (2) to identify key application areas which could highly impact the AEC industry. This goal is accomplished by classifying the literature in categories arising from the literature and defined by the authors. Finally, a summary of the important points and conclusions are presented.

The remainder of this paper is as follows: our selection of four journals and subsequently 259 articles on the topic of virtual reality in the AEC industry (section 2), our review of the articles and identification of their characteristics (section 3), our definition of relevant dimensions for the classification of the articles (section 4), and our classification of the articles in the defined dimensions (section 5). Section 6 presents our conclusion. This research methodology is similar to the methodology used by Rankouhi et al. (2012).

[1] Citation: Rankohi, S. & Waugh, L. M. (2014). Virtual reality in the AEC industry: A literature review. In: N. Dawood and S.Alkass (Eds.), Proceedings of the 14th International Conference on Construction Applications of Virtual Reality, 16-18 November 2014, Sharjah, UAE.

SELECTION OF THE JOURNALS AND ARTICLES

Four diverse prominent academic journals were selected within the domain of construction engineering and management to record the evolution of VR technology in the AEC industry: the Journal of Automation in Construction (AIC), the Journal of Information Technology in Construction (ITcon), the ASCE Journal of Computing in Civil Engineering (CCE), and the ASCE Journal of Construction Engineering and Management (CEM). Selection of these journals was based on their prominence in the field of construction engineering and management research.

A total of 377 articles were found in these four journals using the search phrase "virtual reality." After excluding articles that were published in 2013 (due to the lack of a full year at the time when the search was conducted) and articles such as calendars, editors Notes, subject index, and content of volume the total number of selected articles was 259. The article selection process and article's distribution among the four journals is depicted in Figure 1.

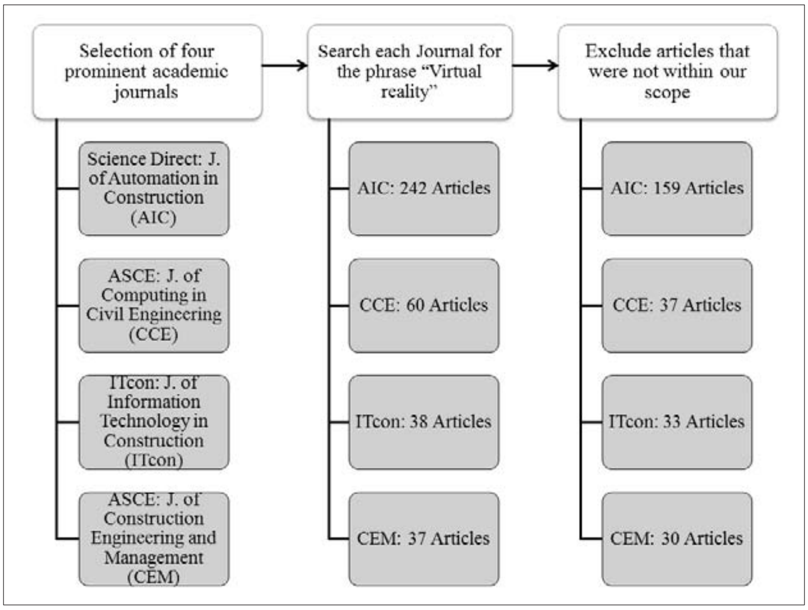


Figure 14: The process of selecting journal articles

REVIEW AND IDENTIFICATION OF THE ARTICLE CHARACTERISTICS

The numbers of articles by journal and by year are depicted in Figure 2. Among the four journals, AIC has the highest percentage of articles (61%), while CCE, ITcon and CEM have 14%, 13% and 12% respectively. The maximum numbers of articles in a single year were published in 2012 (52 articles or 20%).

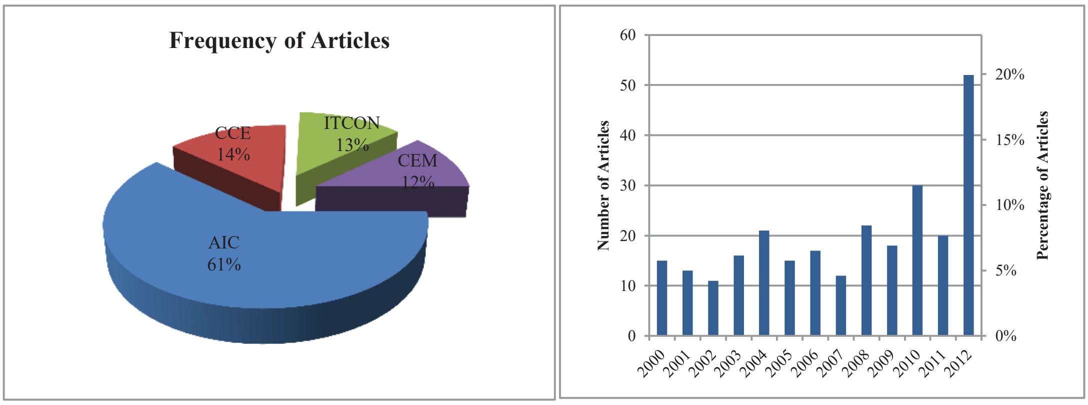


Figure 15: (a) Total percentage of articles by journal; (b) Total number of articles by year

The final characteristic identified in this section is the number of articles based on the first author's country of residence. Of 259 articles, first authors residing in the USA (65 articles) have the highest number of the articles about VR technology in the AEC industry among the other countries. The total number of articles by first author's country of residence is shown in Figure 3. Other consists of countries with one or two articles.

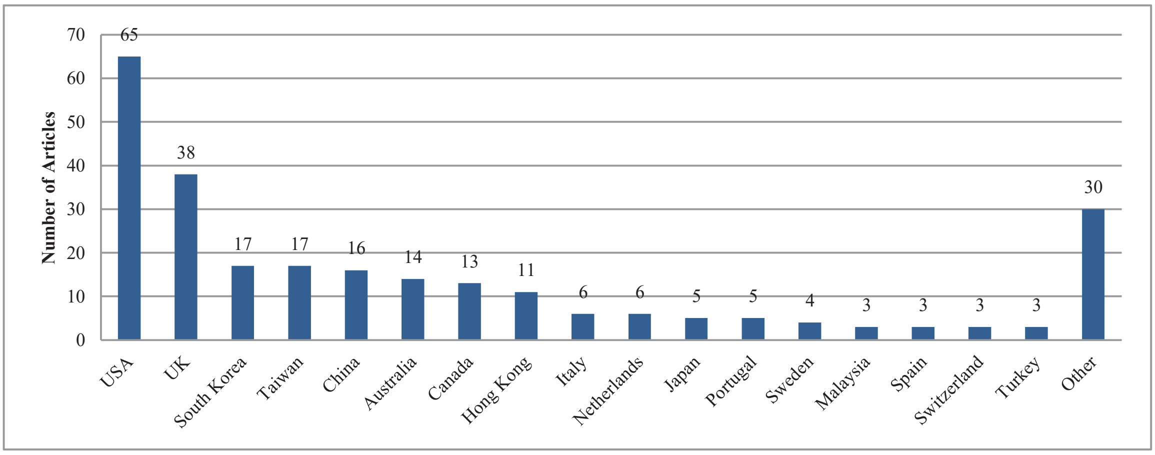


Figure 16: Total number of articles by first author's country of residence

DEFINITION OF CATEGORIES

To better understand and further segregate the literature, we defined dimensions to be used in this paper; each article was then compared to these defined dimensions for identification of its principal focus area or to determine the percentage of articles including reference to that classification.

Articles are classified based on their *improvement focus* in four categories: (1) industry, (2) organization, (3) AEC projects, and (4) individuals. Moreover organization category is divided into three subcategories of organization type including: (a) facility owner, (b) designer, and (c) contractor.

In the construction industry various *project types* can benefit from VR technologies including: (1) municipal/infrastructure e.g., evaluation of dynamic city models and an emission model for transportation (Aschwanden et al., 2012), (2) residential e.g., virtual reality for designing and customizing mass housing (Duarte, 2005), (3) building/commercial e.g., visualizing high-rise building construction strategies (Russell et al. 2003), (4) heavy/highway e.g., developing virtual reality system for optimized simulation of road design data (Kang L. S. et al. 2010), and (5) Industrial e.g., application areas for augmented reality in industrial construction (Shin D. H. et al. 2008).

Project phases or project sequences which should be completed to reach project final goals and objectives are: (1) feasibility and initiation, (2) design development, (3) procurement, contract and pre-construction, (4) construction, (5) commissioning, (6) maintenance, and (7) renovation and reconstruction.

Virtual reality technologies have a wide range of *target audiences* in the AEC industry including: (1) Design team, (2) project managers, (3) workers/machine operators, (4) building systems engineers, e.g., structural, mechanical, and electrical engineers, (5) inspector/safety officer, (6) project end users, and (7) students. If an article proposed a change in the work of one of these audiences, it was assigned to that subcategory for this classification.

From a *stage of technology maturity* perspective, the articles are divided in five categories: (1) theory, (2) framework, (3) sub-system technical issues, (4) proposed system development, (5) production and system application.

Virtual reality technologies have various roles in the construction industry. The VR *technology role* dimension is divided in seven categories as follows: (1) visualization/simulation e.g., a virtual prototyping system for simulating construction processes (Huang et al. 2007), (2) communication/collaboration e.g., improving megaprojects through collaboration with ICT (Chung et al. 2009), (3) education/training e.g., educational simulation in construction (Nikolic et al. 2011), (4) information access/evaluation e.g., improving spatial ability using a web-based: virtual environment (WbVE) (Rafi et al. 2005), (5) safety/inspection e.g., VR-based program for conveyor belt safety (Lucas et al. 2008), (6) progress monitoring e.g., application of D4AR for construction progress monitoring (Golparvar-Fard et al. 2011), and (7) information modeling e.g., on-site building information retrieval by using projection-based augmented reality (Yeh et al. 2012).

Virtual reality utilizes different *technologies' types* in construction industry. From a user experience perspective VR environments are: (1) immersive or (2) desktop-based, i.e., non-immersive. Devices such as HMD and data-gloves create immersive VR systems, in which users feel immersed in a virtual environment just as they usually feel in a real environment. From a technology delivery perspective virtual reality devices are classified as (1) web-based or (2) standalone.

CATEGORIZATION OF THE ARTICLES

This section discusses the classification of the current state of VR technology literature in the AEC industry. The articles are classified based on their principal focus and each article is counted once (except for section 5.5 where articles may be counted more than once).

Improvement focus

Figure 4 illustrates the number of articles within each improvement focus category. As shown, 134 articles (52%) have a principal focus on AEC projects, while 67 articles (26%) have a principal focus on individual in construction industry. In addition, 36 articles (14%) and 10 articles (15%) have a principal focus on AEC industry and organization respectively.

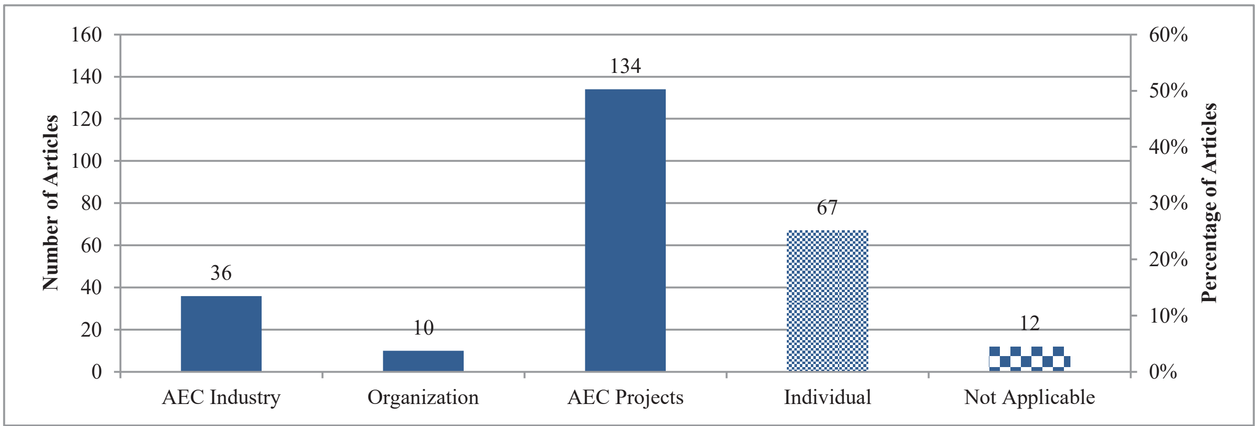


Figure 17: Number of articles by improvement level

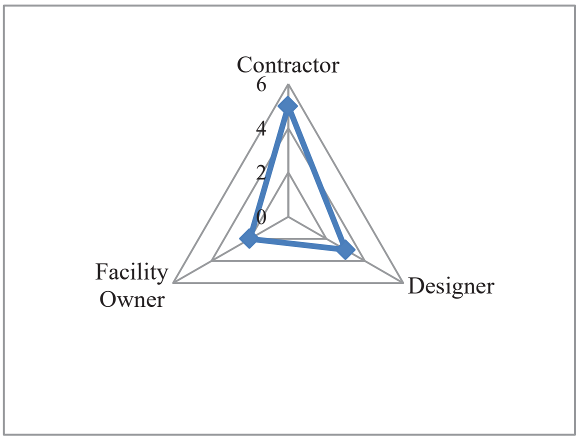


Figure 18: Number of articles by organization type

Figure 5 presents the number of articles within each organization type category. As shown, among those 10 articles with an improvement focus on organization, five articles have a principal focus on contractor, while three articles focus on designers, and two articles focus on facility owners.

Industry sector

Figure 6 presents the number of articles within each industry sector dimension. As shown, 81 articles (31%) have a principal focus on building/commercial as an industry type for VR technology. Heavy/highway, municipal/infra-structure, industrial, and residential categories have 17 articles (6%), 12 articles (5%), 11 articles (4%) and 9 (3%) articles respectively. Seventy-three articles focus on multiple areas while these categories were not applicable for 68 articles.

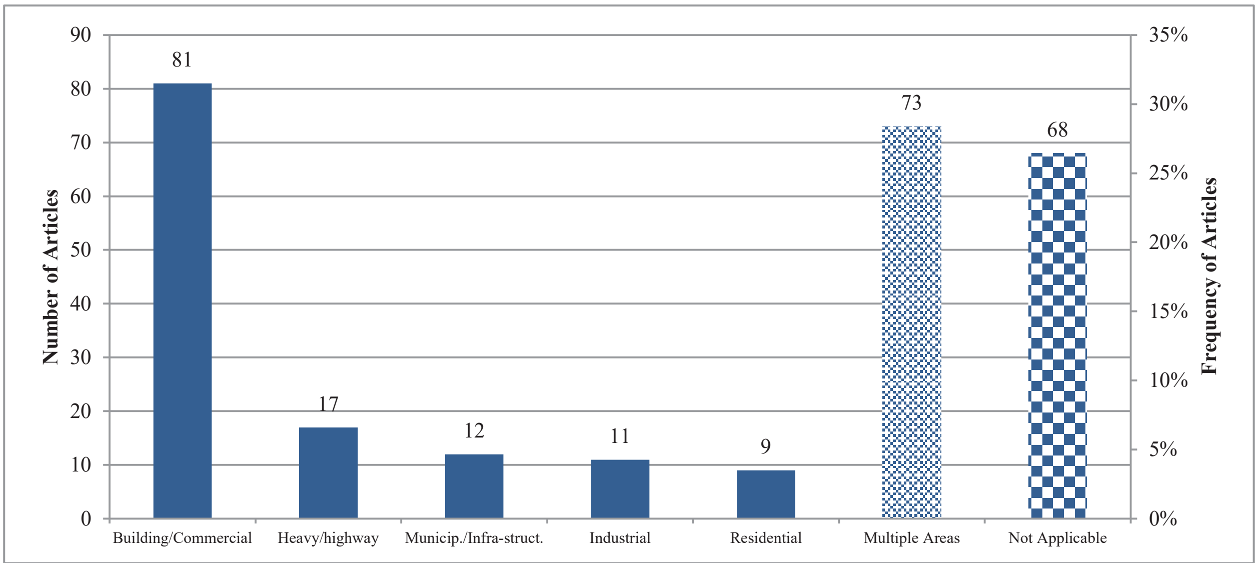


Figure 6: Number of articles by industry sector

Project phase

The number of the articles by project phase is depicted in Figure 7. Eighty articles (31%) have a principal focus on the construction phase and 51 articles (20%) have a principal focus on the design phase.

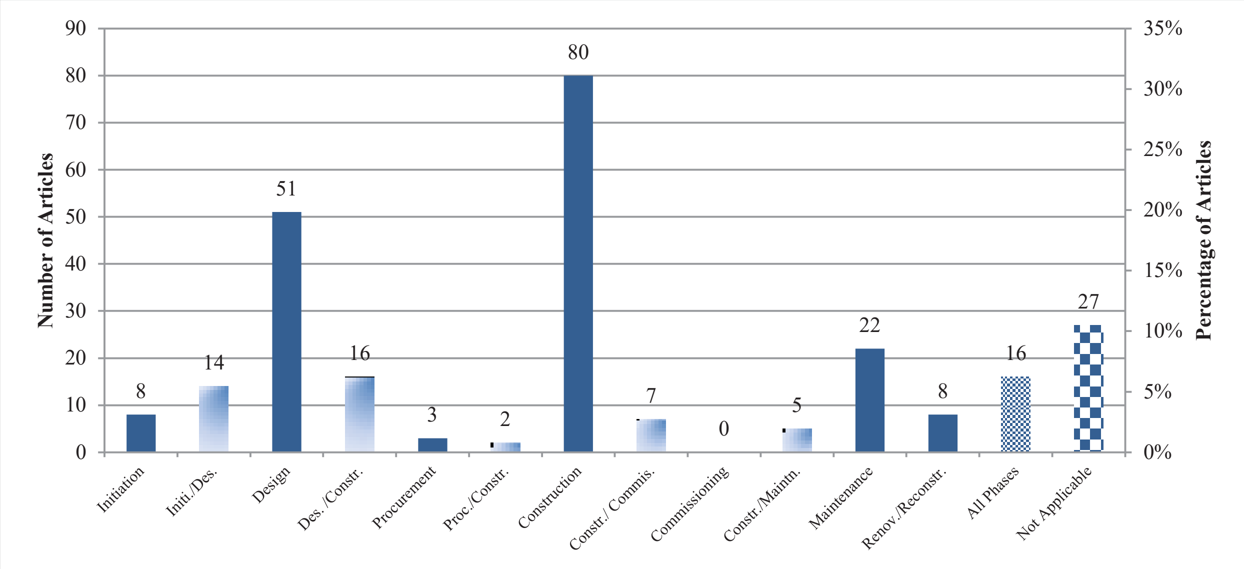
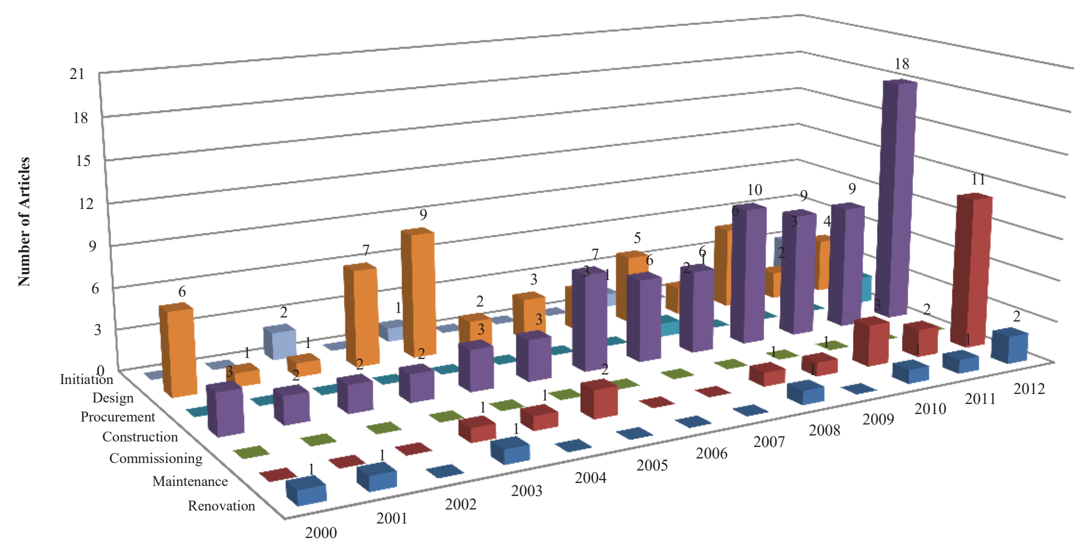


Figure 7: Number of articles by project phase

Figure 8 illustrates the number of articles for each project phase by year of publication. In this diagram articles with a focus on multiple phases are excluded (reducing the total to 172 articles). The highest number of articles in a single year is for the construction phase in the year 2012. The focus on the maintenance phase of a project started with zero articles in 2000 and reached its highest number (11 articles) in the year 2012. Figure 7 and Figure 8 show that the highest number of articles occurs in the design and construction phases of a project for VR technologies.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Renovation	1	1	0	1	0	0	0	0	1	0	1	1	2
Maintenance	0	0	0	1	1	2	0	0	1	1	3	2	11
Commissioning	0	0	0	0	0	0	0	0	0	0	0	0	0
Construction	3	2	2	2	3	3	7	6	6	10	9	9	18
Procurement	0	0	0	0	0	0	0	0	1	0	0	0	2
Design	6	1	1	7	9	2	3	3	5	2	6	2	4
Initiation	0	0	2	0	1	0	0	0	1	0	1	0	3

Figure 8: Number of articles by project phase and year of publication

Target Individual Audience

In this section only instead of giving the number of articles with a "principal focus on" a subcategory, we report the percentage of articles "including reference to" that subcategory, since in this section each article may refer to more than one subcategory. Figure 9 presents the percentage of articles by target audience. The results indicate that (among others) 36% of articles include reference to design team as the target audience, 33% refer to project managers, and 26% refer to worker/machine operator.

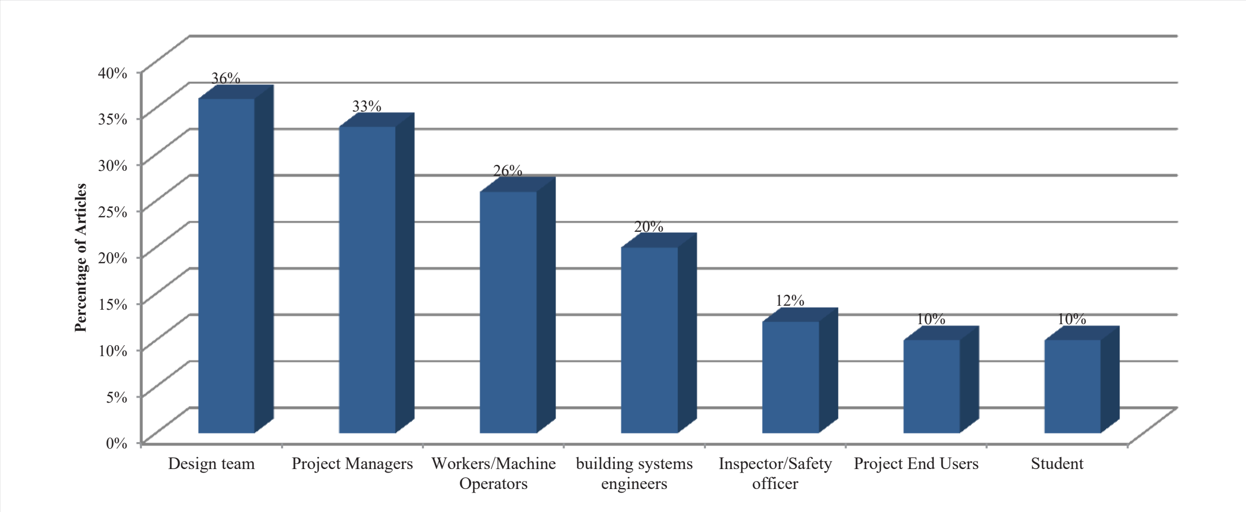


Figure 9: Percentage of articles by target audiences

Stage of Technology Maturity

Figure 10 illustrates the number of articles within each stage-of-technology-maturity subcategory. As shown, 78 articles (30%) have a principal focus on virtual reality application demonstration in AEC industry, while 61 articles (24%) and 35 articles (14%) have a principal focus on VR proposed system development and framework respectively. Forty-three articles have a focus on multiple areas (i.e., more than one of the previous stages); these multiple areas are typically a combination of framework and system application.

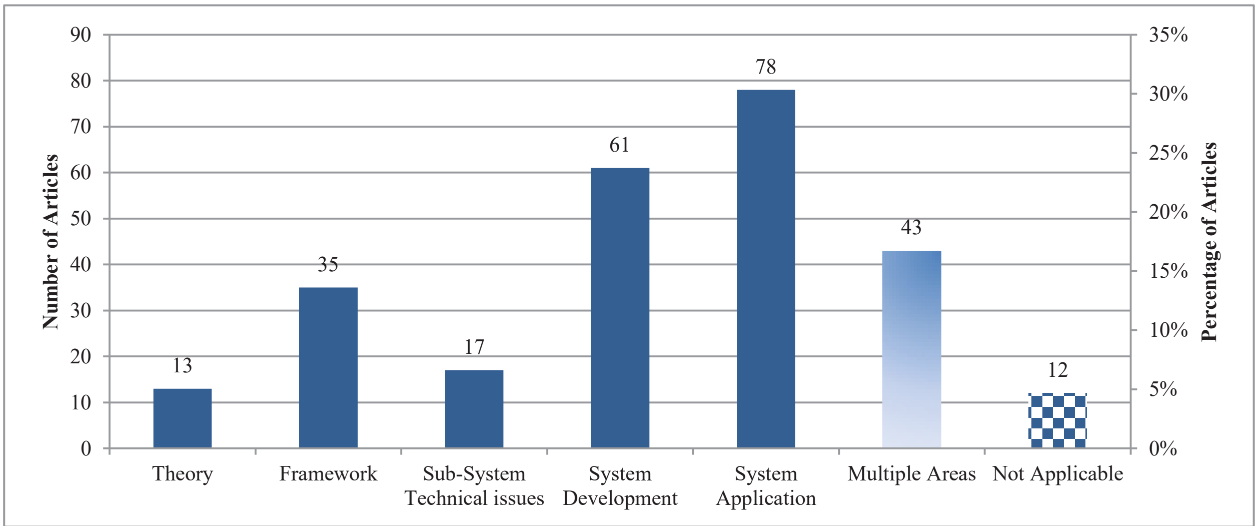


Figure 10: Number of articles by stage of technology maturity

Technology Role

Figure 11 presents VR "technology's role" in the AEC industry. As shown, 62 articles (24%) have a principal focus on simulation/visualization as VR technology role. Communication/collaboration, education/training, information access/evaluation, safety/inspection, progress monitoring, and information modeling have 42 articles (16%), 31 articles (12%), 30 articles (11%), 27 articles (10%), 17 articles (7%), and 16 (6%) articles respectively. Thirteen articles focus on multiple application areas while these subcategories were not applicable for 21 articles.

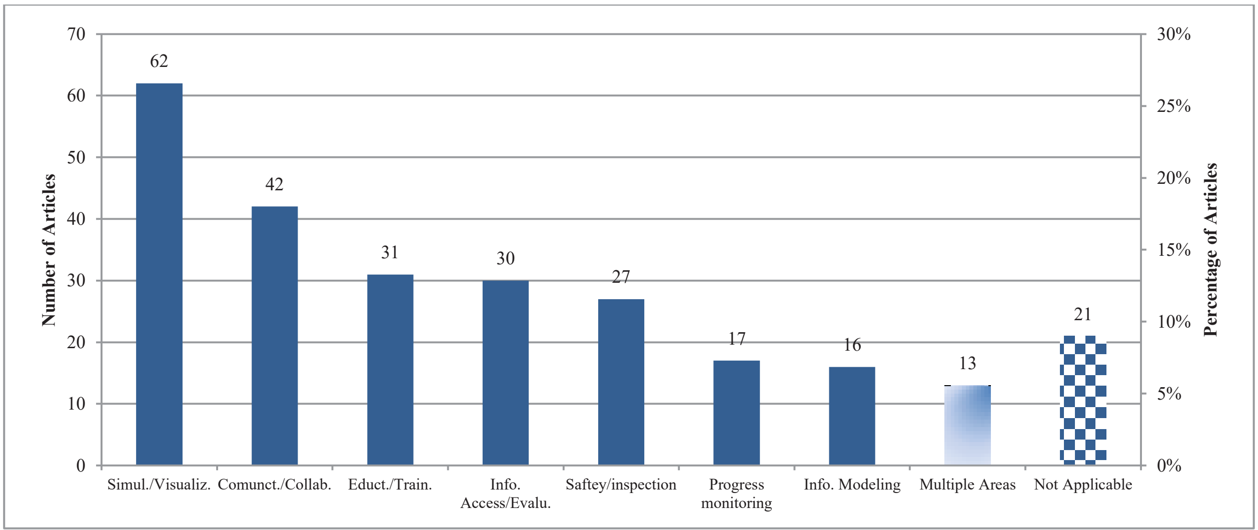
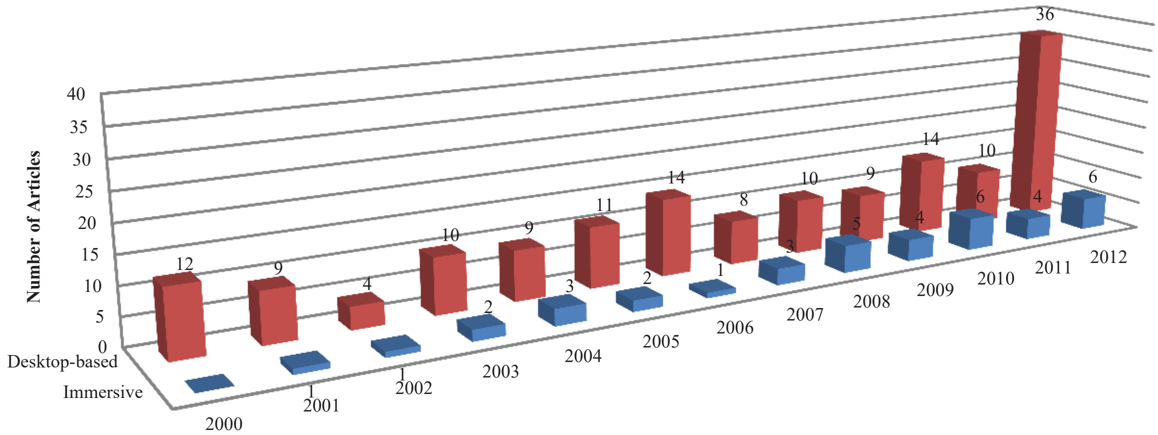


Figure 11: Percentage of articles by technology role

Technology type

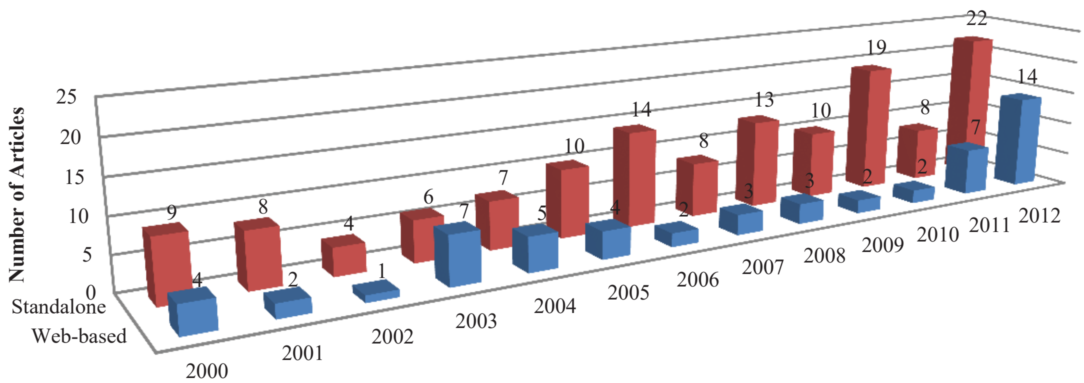
Within the technology type dimension, 38 articles (15%) had a principal focus on immersive VR technologies, 156 articles (60%) had a principal focus on desktop-based VR technologies, while 65 articles were not applicable. Figure 12 presents the number of articles with immersive and desktop-based technologies as a principal focus by year.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Immersive	0	1	1	2	3	2	1	3	5	4	6	4	6
Desktop-based	12	9	4	10	9	11	14	8	10	9	14	10	36

Figure 12: Immersive and desktop-based VR technology by year

Figure 13 presents the number of articles within the technology type category that had a principal focus on web-based and standalone VR technologies in the AEC industry. Fifty-six articles (22%) had a principal focus on web-based VR technologies, while 138 articles (53%) had a principal focus on standalone VR technologies. Sixty-five articles (25%) were not applicable to this category.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Web-based	4	2	1	7	5	4	2	3	3	2	2	7	14
Standalone	9	8	4	6	7	10	14	8	13	10	19	8	22

Figure 13: Web-based and standalone VR technology by year

CONCLUSION

A structured methodology was used to identify 259 articles on the topic of virtual reality from four prominent AEC industry journals. In addition to statistics on the counts of articles by year and the first author's country of residence, seven interpreted dimensions were developed to classify these articles. Figure 14 displays the counts of articles for each of the categories within these dimensions. The category with the highest count (within a dimension) is shown in bold and categories with obviously increasing trends are designated with an up arrow.

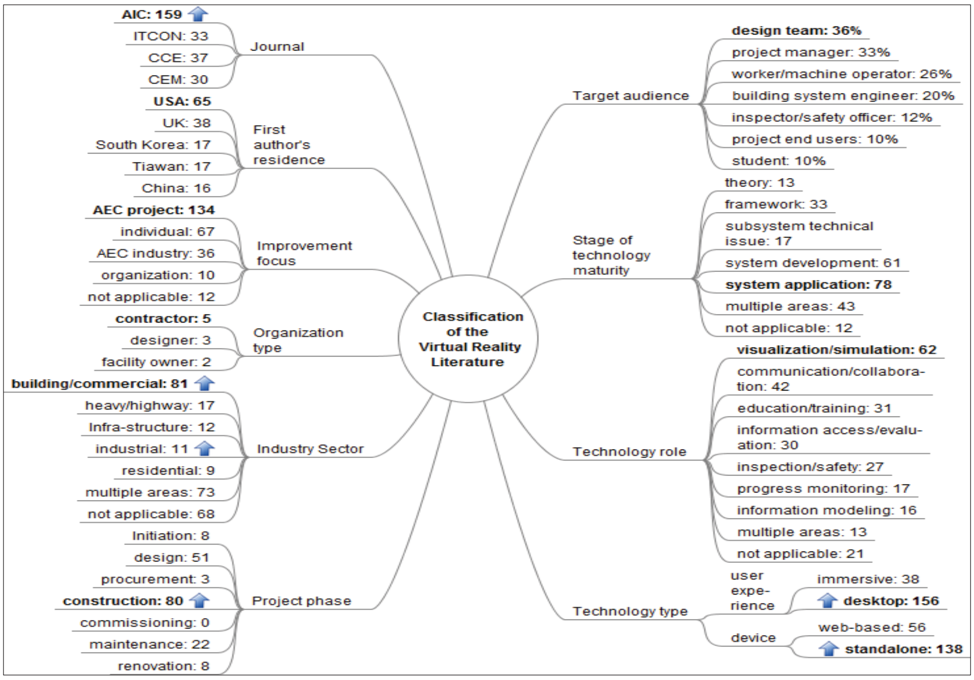


Figure 14: Literature Review Summary

The following results are concluded for the categories shown in Figure 14.

- Journals: AIC has the highest overall number of articles among the journals, while the other journals roughly split the remaining 39% of articles. The number of VR articles published in these four journals in a single year, increased abruptly in 2012 to over 50 from a maximum of 30 in previous years.
- First authors: The USA and UK (comprising 40% of all papers) were the dominant residence of the first authors.
- Improvement level: The most frequent focus was projects, rather than industry, organization, or individual.
- Industry sector: Over 30% of all articles published (or over 60% of articles that were determined to have an industry sector) focused on the building/commercial sector.
- Project phase: Although the design and construction phases dominate with approximately 20% and 30% of all articles respectively, a large number (over 20%) of articles address multiple phases.
- Target audience: Approximately one-third of the articles made reference to the design team with approximately one-third also making reference to project managers and approximately one-quarter making reference to on-site workers (in this case, the same article could be counted in more than one category).
- Stage of technology maturity: The largest number of articles focus on VR system application in the AEC industry, with the system development being next and with these two categories comprising approximately half of all the articles. Few articles had theory or technical issues as their principal focus.
- Technology role: The most frequent focus is on visualization/simulation and communication/collaboration.
- Technology type: Sixty percent of the articles had a principal focus on desktop-based VR technologies. From the perspective of web-based and standalone technologies most of the articles discussed standalone technologies.

Table 1 provides a complete list of the categories for which there was a significant and consistently-increasing trend. There were no categories for which the number of articles was consistently-decreasing over the 12 year period.

Table 7: Significant trends

Dimension	Category	2000	2012	Factor
Journal	AIC	11	26	2.4
Industry sector	Building/ commercial	5	20	4.0
Industry sector	Industrial	2	9	4.5
Project Phase	Construction	5	21	4.2
Device	Standalone	9	22	2.4
Total number of articles	NA	15	52	3.5

We speculate that the stage of maturity of VR technologies is the key factor influencing several of the trends concluded above; our interpretation is as follows. Although VR technologies provide proven benefits especially in the areas of visualization/simulation and communication/collaboration, these benefits are not yet widely adopted by AEC industry participants nor have they been incorporated into industry-wide workflow processes. As a result, industry participants choose to pilot (i.e., system development and application) VR technologies on a few projects rather than adopting or piloting the technology across their organization.
Building/commercial projects provide a good test bed for visualization and communication of different perspectives of a project, since these projects typically entail more complexity and need for integration than an infrastructure, heavy/highway, or residential project. However, we speculate that use on industrial projects will grow rapidly as confidence is gained. The uniform distribution of target audiences among the design team, the project management team, and on-site personnel reflects integration being the essential purpose of VR technologies. We predict continued growth in the use of internet and web-based devices to enhance integration of perspectives. We also speculate that the cost of immersive hardware is, and will continue to be, an impediment to its widespread use.

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PART II: BIM & VR IN EDUCATION, LEARNING & COLLABORATION

IMPLICATIONS ON FACILITATING INTERACTION IN PUBLIC HEARINGS WITH VIRTUAL MODELS[1]

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ABSTRACT: *Interaction is one of the key elements in current design practice. When project stakeholders have prosperous and balanced interaction with numerous disciplines involved in design formation and decision-making, and interaction towards end-users is fruitful to both directions, this usually leads to a successful project.*
Visualisation is seen as an efficient way to reduce communication difficulties. Virtual reality in particular, has been found to offer promise for design visualisation to convey messages between different stakeholders. In other words, visualisation lowers a threshold to participate, even with varied backgrounds. This paper presents findings from observations and experiences in three public hearing events organised in a large infrastructure construction project in Finland. The intention was to facilitate citizen interaction via the use of virtual models in communicating plans, whereas design drawings and maps for communication are simultaneously present as well.
Activity theory was used as a starting point when the resulting interaction was to observe and the obtained data was analysed. The empirical findings comprise observations (138 participants) in three events, from which the data was gathered using virtual model questionnaire (sample 41) and virtual model in tablet questionnaire (sample 11). Results indicate that a clear majority of those involved has positive attitude towards the use of virtual models. Based on questionnaires, virtual model as 'instrument' seems to change the 'division of labour'. Interestingly, the more models are used the more benefits participants seem to experience and satisfaction to event increases. However, virtual models seem to be a rather sensitive matter. Other supplementing 'instruments' need to be used to facilitate communication successfully. It was found out that citizens have more courage in events to discuss in smaller groups instead of a large audience. Thus, it is suggested that group work should be the main working practice whenever possible, since this forms an effective work method for interaction between citizens and planning team. New technologies provide interesting opportunities for non-expert interaction to facilitate interaction. The aim for future is to find a meaningful way to balance group dynamics with more communicative work practice.

KEYWORDS: *Large project, Virtual Reality, Public hearing event, Activity theory, Interaction, User feedback*

❖ INTRODUCTION

A continuous flow of public projects is required for the development and maintenance of built environment infrastructure. Performance, achievements and decision-making in those projects are of public interest, and, thus easy access towards relevant information sources is required in a growing manner. Project management community has recognized the need for systematic stakeholder management that has nowadays presence in the leading industrial project management standards such as APM (2012), IPMA (2006), ISO (2012) and PMI (2013). External stakeholders can be significant sources for project complexity where for example a construction project can suffer from the social opposition of the local community if this aspect is not managed successfully. Proactive moves such as making stakeholders' knowledge accessible to others can provide clear improvements. Regular knowledge sharing sessions can be very useful platforms for creation, integration and transfer of specialized knowledge and generation of innovative ideas (Hadaya and Cassivi, 2012).
Interaction is one of the key elements in current design practice. Changes during a planning process affect large amounts of people both directly and indirectly. When there are decisions to be taken about public matters or changes planned to common environment, the inhabitants have basically a legal right to express their views on the matter. Participation to decision processes is in western society considered as an important part of civil liberties and forms a cornerstone of functional democracy. The idea of participation in democratic urban government has been around since the Athens charter of 1933 (Le Corbusier, 1943/1973) and planning theory has discussed participation and its impacts already for example in 1960's (Davidoff, 1965; Arnstein, 1969). In

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Finland, the building act states that interaction with citizens is obligatory (Finnish Land Use and Building Act, 1999, 62§-65§). References to similar practices are present also for example in UK, Austria, Israel and USA (Strobl, 2006; Alfasi, 2003; Innes and Booher, 2000).

Involving users is beneficial for planning and civil engineering projects. The statutory participation in planning and civil engineering projects is in Finland defined as the right to the citizen to have the information about the plans and the right to submit written objections to the matters if they are negatively affected by the planned actions (Finnish Land Use and Building Act, 1999). It has turned out that this kind of "participation" indeed created a lot of objection and complaints to be solved, which delays the planning and building processes. Therefore, methods involving the citizens in more collaborative ways are employed extensively nowadays. It is typical in Finland not only to present almost complete plans to the public, but also to start discussion already earlier in project to give the public a possibility to express ideas and opinions when developing the plan. The interaction aims at passing knowledge efficiently between project stakeholders, affected legal entities and the general public usually takes place in a series of so-called public hearing events.

As design methods and tools have been developing towards exploiting 3D visualisation and model-based approaches, such as building information modeling (BIM), tools are enabling presentation of designs and plans for public audience. Technological solutions for user interaction have been a popular research topic (e.g. Mobach, 2008; Wahlström et al, 2010). Furthermore, results based on studies of experimental test settings have been presented (Al-Kodmany, 1999; Porkka et al., 2012 & 2013; Castronovo et al., 2013). On the other hand, live project meetings or public hearings taking advantage of interactive models and data sources have been studied in a very limited manner. This paper presents a real life case study of a civil engineering project in Finland applying 3D virtual model in public hearings and interaction workshops with the citizens. The aim was to draw conclusions about i) how citizens find these new methods, ii) are they helpful in facilitating understanding and/or approving with the design. The paper focuses on the observations made in three public hearing events utilising virtual models in communicating plans to public. First, we set out the key theoretical principles for interaction. Then, basic information is described for observed public hearing events. The methodological approach of activity theory has been used in observing the interaction. Finally, we discuss the observation results and findings from questionnaires, and draw conclusions on utilising visualisation technology and how it actually influenced on interaction and group dynamics.

INTERACTION TOWARDS PUBLIC

When project stakeholders have prosperous and balanced interaction with numerous disciplines involved in design formation and decision-making, and interaction towards end-users is fruitful to both directions, this usually leads to a successful project. Users have during past decades evolved from objects of studies to active collaborators in design. The focus of participation has in the same time shifted more on the exploration and identification of presumably positive future opportunities than on the identification and reducing of adverse consequences (Sanders and Stappers, 2008). To get a public approval for communal development, it is important to interact with the public since the early stages of planning. Irvin and Stansbury (2004) have reviewed citizen participation literature and listed the advantages of citizen participation as: education of the public, political suasion, empowerment, breaking gridlock, avoiding litigation costs and better environmental management.

However, Irvin and Stansbury (2004) have also listed citizen participation disadvantages and barriers. One of the major challenges is wide array of participants involved to process, and a communication gap that exists between the various 'user groups'. Co-design languages that support and facilitate the many varieties of cross-cultural communication are highly valuable (Sanders and Stappers, 2008). One such "languages" is visualisation.

Interaction via virtual models

When a citizen is asked to consider planning options, or examine detailed plans, the response in general may be an embarrassment and a surprise. Abstract notations have potential to be confusing to non-experts (Alfasi, 2003). As a matter of a fact, many end-users tend to have a limited ability to read and understand content from maps. Thus, the way how project information is represented can have a significant effect on understanding the design and providing meaningful feedback (Kalisperis et al, 2002; Castronovo et al, 2013).

Visualisation is seen as an efficient way to reduce communication difficulties in many studies (e.g. Kalisperis et al, 2002; Wissen et al, 2008). Virtual prototypes have a great similarity to the real world and 3D representations have also been employed to convey information to the general population through public hearings, workshops, and the Internet (Lai et al, 2010). Virtual reality, in particular, has been found to offer promise for design visualisation to convey messages between different stakeholders (Whyte, 2003; Maldovan and Messner, 2006; Porkka et al, 2012). This is supported Al-Kodmany (1999), who studied three visualisation methods employed in participatory planning processes. He found out that all techniques helped in facilitating common understanding and consensus for the participants, but stressed out the importance to avoid technical problems. Lange (2005) has stated that visualisation can be used in a classic top-down approach, communicating information to public, as well as from bottom-up approach, where citizens are being consulted for ideas and participate in decision-making. In other words, visualisation lowers a threshold to participate even with people with varied backgrounds.

CASE STUDY

The case is an on-going 32-kilometer long motorway section modernization project in Finland. The study incorporates a road plan development phase that a governmental organization ordered from consultants. Appointed experienced professionals were hired to follow up together with client. For the particular motorway section, transport forecasts presume an increase of 130-140% in traffic volume by year 2040. The road plan introduces solutions, required traffic schemes and necessary land plots required for construction (The Finnish Transport Agency, 2010). Citizens have given a significant amount of feedback in public hearing events.

Subject of Research

Public hearing events and their observation were made during a six months period. We have used activity theory from social sciences to investigate collective activity and interaction. The activity system model with seven key elements was used to analyse micro level individual participation from seven interlinked elements; *subject, object, outcomes, instruments*, *community, division of labour*, and *rules* (Engeström's, 1999 & 2010; University of Helsinki, 2012).

Model-based working was extensively used in the motorway project. Virtual model was adopted to citizen communication, together with design drawings and maps as well. Before the events took place, hypothesis of researchers was that virtual reality has positive influence on general event satisfaction. Besides, an expectation was that visualisation, when compared to utilising maps only, helps to understand solutions more thoroughly. We observed that project team appreciated highly the interaction with occupants and landowners. The interaction had continued nearly a decade, and during the road plan development communication with topics and locations was documented. Public hearing events were held at evenings, and on same day (between 9:30 and 17:00) planners were available for discussions with occupants, landowners and other interest groups.

The character and arrangements in three hearings were heterogeneous but had similarities (see Fig. 1). To shorten the representation, we mention those as event 1, event 2 and event 3. Events 1 and 2 presented the current road plan status in a local conference room, while event 3 introduced thoroughly the final road plan at local school's sport hall. Lengths of events ranged from 2 to 3 hours, ending to a voluntary based questionnaire. Event 1 introduced the status the plan as a moving target to 62 participants, fifty-fifty distribution to regions occupant and landowners. The event consisted from presentations, short virtual model introduction and group discussions by maps. The model was not that detailed in event 2 that was a workshop focusing on particular area in order to raise awareness and discussions with citizens. In event 2 vast majority of 16 participants were landowners and over half of the time was spend to group discussions by maps and virtual model was shown briefly. After the workshop, a field trip was organized to interested citizens piloting tablet application that enabled visualization of localized plans. Third event was the final public event of road planning phase to show almost complete and well prepared materials. The role of virtual model was also clearly larger than in the previous events. A sample of 58 persons joined event 3 to see program that included presentations, a 10-minute video produced from the virtual model, the virtual model and group discussions. Virtual presentations were also recorded. After a promising tablet test in event 2, researchers proposed to the client a tablet experiment. The test comprised two sub models from planning area loaded to a tablet and an opportunity to occupants to try new technology wit guidance. To get user feedback, we observed tests and captured opinions with a separate voluntary questionnaire.

Fig. 1: Photos from public hearing event observed - road plan review up left (event 1), road plan workshop up right (event 2) and final road plan review below (event 3). Photos are courtesy of Janne Porkka.

RESULTS AND OBSERVATIONS FROM THE EVENTS

The selection of virtual reality application used was justified by two reasons. First, since the project is extensive the solution had to be compatible to two model-based design systems used. Second, the amount of revisions of design is enormous, and therefore, generation of virtual model had to be at least semi-automated. Thus, Vianova's Novapoint Virtual Map (Vianova, 2013) was used in generating and presenting the virtual model. The solution enables a semiautomatic conversion of multi-disciplinary and complex plans into a virtual presentation. For this particular case, the road plan was a combination model including sub models from different design disciplines. The presentation consisted from "driving" or "flying" through plans and simultaneous explanation of planned content. Pre-defined views were used in most important sections of motorway plan.

The participants in studied events were occupants, cottage owners, landowners, actors in region and media representatives. Before the event, researchers also participated to a planning meeting to discuss arrangements. We agreed together not to record public hearing events due to a possibility that formal procedures might diminish the level of voluntary-based public interaction. Event began with traditional presentations usually held by client, consultants and affected legal entities. Each presentation finished to a discussion where citizens had an opportunity to comment or ask questions. This interaction led to valuable contributions throughout the project. Client actually said that they aim to answer every single comment. During events researchers made field notes and took photos, focused attention to track arrangements, event flow, presentations and interaction.

At the end of each public event a voluntary-based survey was made with questionnaire to participants. The questionnaire scanned opinions towards virtual models and consisted of three background questions (age, sex and role) and target questions formulated as positive sentences. The format of target questions was threefold; Likert-style (7 levels), yes-no and open questions were used. Since the main aim was to achieve better understanding on how people understand plans and whether a media used in communication has an effect on results, we used primarily the same questions to enable comparisons between the events. We reflect perceived results back to macro level project considerations.

Statistics about three public hearing events are presented in Table 1. The empirical findings comprise observations from three public hearing events (138 participants), answers on virtual model questionnaire (sample 41) and answers on virtual model in tablet questionnaire (sample 11).

Table 1: Summary of general information in three observed public hearing events.

Event	Type	Participants (appr.)	Questionnaire sample	Virtual model presentation time (min.)	Event length (min.)
Event 1	Road plan review	62	18	6	120
Event 2	Road plan workshop	16	10	5	130
Event 3	Final road plan review	58	13 (+11 tablet)	51 (+ 12 video)	190

Public's response to use of virtual model

The virtual model for presenting road plans was used more profoundly in events 1 and 3 than in event 2. The time used for virtual model presentation in events 1 and 2 was approximately only 5-6 minutes, but based on the observations, in event 1 the virtual model was first introduced to the audience in previous presentations by showing pictures of the virtual model. More importantly, the public was also able to examine the virtual model *after* the actual presentations during group work session in events 1 and 3, and guidance for using the model was given when needed as well. In event 2, neither introduction nor possibility to examine the model with an expert was offered. Furthermore, in event 3 the time used for virtual model presentation with discussion was 51 minutes. Before the virtual model, a ten-minute informative project video was presented to audience. However, a lot of information was packed into the video. The division of labour with virtual application was slightly different in earlier two events. In third event two consultants presented through the final road design while a third person navigated model. Presenters spoke by turns and used pointer to clarify messages.

The statistics from the questionnaires indicate that the more effort (including introduction, guidance and time) was put on presenting the virtual model, the more the model was considered as suitable and desired for examining the road plans. In event 2, 33% of the people strongly agreed or completely agreed with the statement *Virtual model was well suitable for examining plans*, whereas in events 1 and 3 approximately 80% strongly agreed or completely agreed (see fig. 2).

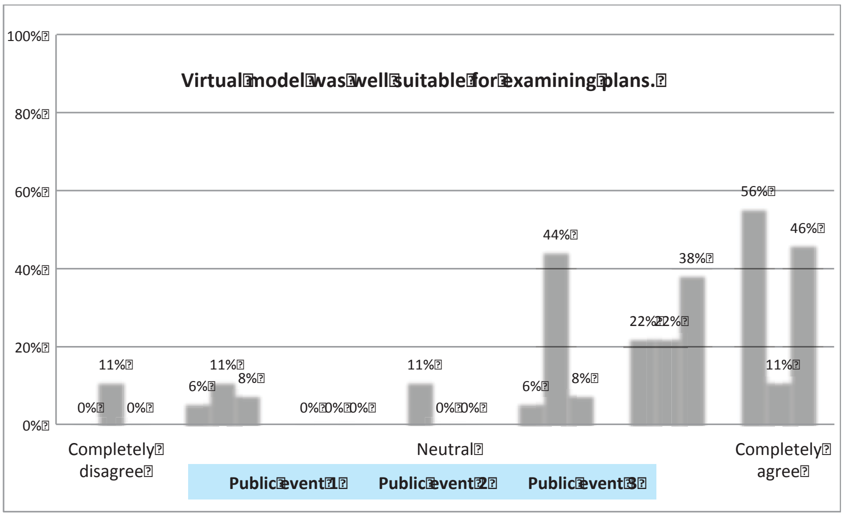

Fig. 2. Suitability of virtual model to examine plans.

Furthermore, with the statement *I am happy to familiarize myself with the plans with the help of virtual model in the future*, 78% of the people in event 1 and 62% of event 3 strongly agreed or completely agreed. In event 2, the number was less than a half, 44% (see Fig 3).

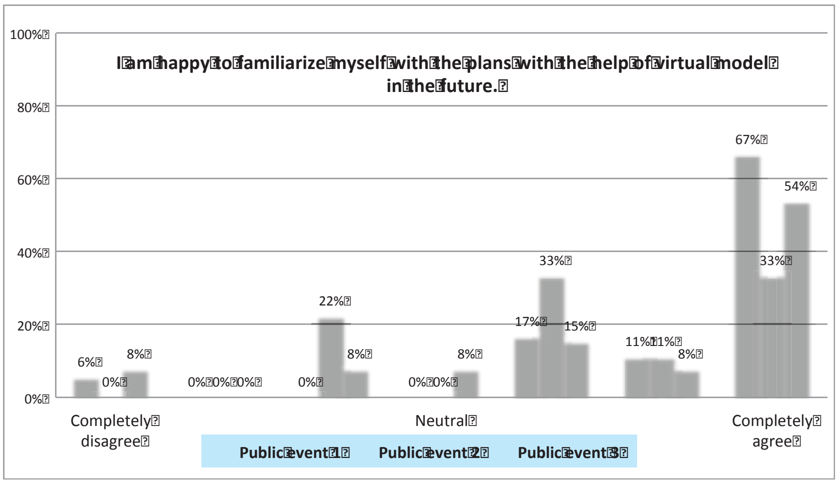

Fig. 3: Willingness to examine virtual models in the future.

Generally, the public's response was positive and virtual models were well received, especially in events 1 and 3. Furthermore it should be noticed, that significant amount of people in event 2 *agreed* that virtual models are suitable for examining plans (44 %) and they are willing to see the models in the future (33 %). Thus, the very short and not profound presentation with the virtual model wasn't obviously enough to convince the public in event 2, but invoked interest among them. After virtual presentations, group work at maps started. Simultaneously in event 3, there was an opportunity at lobby to test virtual model in a tablet. Tablet included two sub models and researchers guided the use when necessary. There was also a voluntary questionnaire for people trying the experiment.

Virtual model and printed maps as tools of interaction

In all the three events, both virtual model and printed maps were used as tools for visualising the plans. The difference between using these tools was that virtual model was more a device for supporting experts' (consult's) presentation to the audience. The paper maps were mainly used before and after the lecture–like presentations in small groups in order to support the questions and discussion.

Based on the questionnaire results from events 2 and 3 (the statements were not included in the questionnaire in event 1), people seemed to understand the plans well from the paper maps without the support of virtual model. In event 2, with very limited virtual model presentation, 90% answered "Yes" to the statement *I understood the actions based on the map presentation without the virtual model* (10% answered "No"). In event 3 with more profound virtual model use, 75% answered "Yes" and 25 % answered "No" (see Fig 4 on the left). Thus, the increased use of virtual model seemed to increase the number of people who felt they didn't understand the printed maps. In event 2, 30% strongly agreed or completely agreed with the statement *I understood the plans better from virtual model than from maps*. 30% of the public strongly disagreed or completely disagreed. However, in event 3, 69% strongly agreed or completely agreed, and none disagreed (see Fig 4., *right side*).

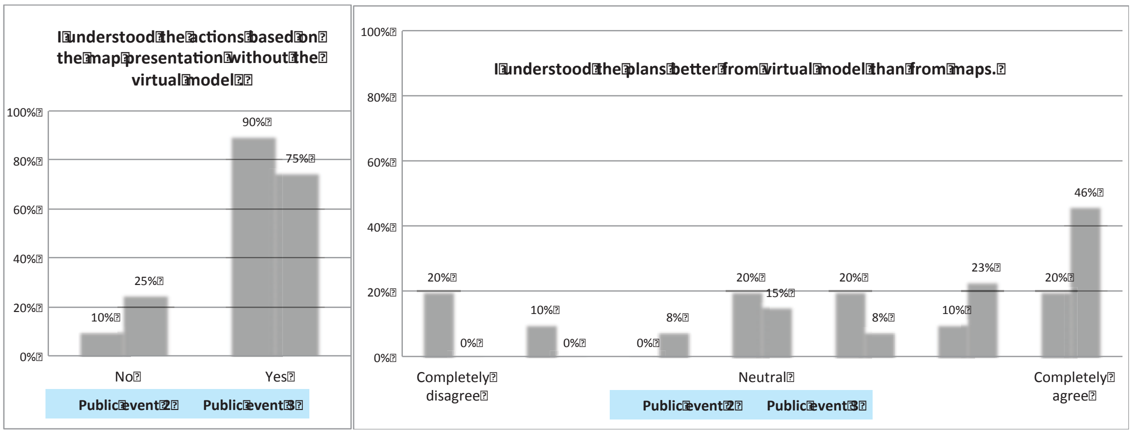

Fig. 4: Understanding the maps without virtual models (*left*) and comparing virtual models and maps (*right*).

These statistics indicate that majority of people felt they understand plans well from printed maps without the support of virtual model. However, the increased use of virtual model seemed to increase the number of people who felt they don't understand printed maps. More importantly, when virtual model was used more, people clearly felt they understand the plans better than from printed maps.

Importance of group work

It was found out that citizens have more courage in events to discuss in smaller groups instead of a large audience. Group work or group discussion was used in every event alongside the presentations. Based on the observations by the researchers, it became evident that interaction was much livelier in small groups than during the presentations given to the whole audience. The groups organised freely around paper maps, which were presenting the plans. It was obvious that paper as an interface, a large paper map in this case, supported discussion (questions, answers, comments) in groups very well. The conversations around these maps were not only between the experts and the public, but also between the different members of the public. During the presentations, the discussion was only between the presenters and the audience members. This richer interaction in small groups might partly explain why people felt they understand the plans from the printed maps so well. It is notable, that in event 3 it was also possible for the audience to examine the virtual model from the large screen with the guidance of an expert. Some people did this, but the most active interaction was clearly around the printed maps. Thus, it is suggested that group work should be intensively used in interaction between citizens and planning team.

Virtual model in tablet

A possibility to use a tablet device for examining the virtual model was arranged in event 3 by researchers. The tablet presentation was separated from the official event agenda and organised during the group work session at lobby. Altogether 15 people visited the tablet stand and 11 answered the tablet-related questionnaire. The average age of the respondents was 62 years and 82% of them were men. The use of the tablets was also observed and comments recorded by the researchers.
According to the questionnaire results, 40 % of the respondents strongly agreed or completely agreed that the tablet application was rousing, and furthermore 30 % agreed. Based on observing users, they often experienced a wow-effect after they had learned to navigate in the model. 73 % of the respondents strongly agreed or completely agreed that the use of tablet was illustrative. One person for example commented that "tablet was better than the model presented on the big screen and the model was easy to understand when you already know the area". The use of the tablet application was not easy for everyone. However, 54 % at least agreed it was easy. It was observed that after the guidance almost everyone was able to move in the model. The first-timers had problems in navigation and moving in plane. Finally, 81 % at least agreed that they are willing to use tablets for examining plans in the future (see Fig 5).

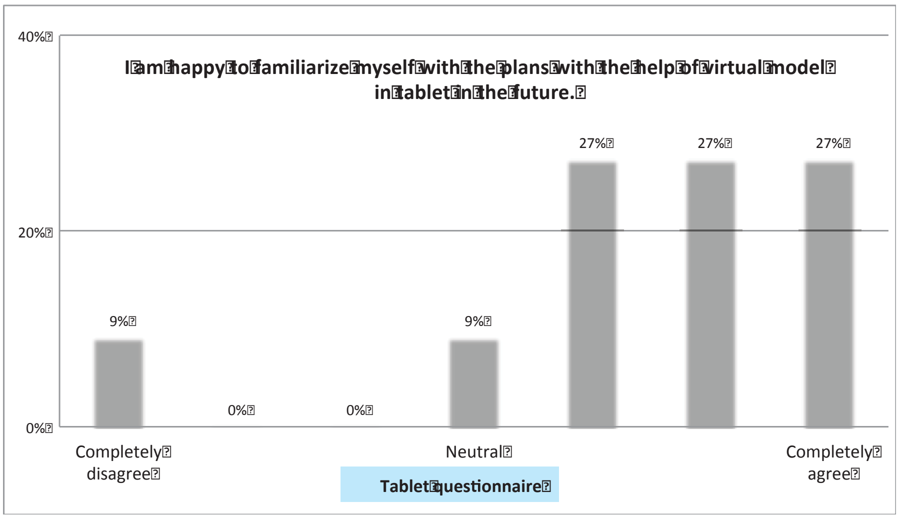

Fig. 5. Willingness to examine virtual models in tablets in the future.

CONCLUSION

New Technologies provide interesting opportunities to involve citizens in more collaborative and participatory ways to planning process. Virtual models have potential to be the next common language between experts and non-experts to facilitate interaction. Results show that 138 person participating in public hearing events, citizens, project team, affected legal entities and media representatives, seemed to have a positive attitude towards the use of virtual models to present plans. We have observed the interaction in a set of three public hearings organised in large civil engineering project. First two events introduced the current version of road plan for 32-kilometer long motorway section to public and the last explained the final plan. In terms of activity theory, the stakeholders' understanding and acceptance of the 'object' of the activity is crucial for successful collaboration. The results indicate that visualising the road plan ('object') with the virtual model increases the publics' (′community′) understanding of the plan and thus have a positive impact on the planning process as a whole.

Based on questionnaires, virtual model as an 'instrument' seems to change the 'division of labour'. The statistics from 41 respondents indicate that the more effort (including introduction, guidance and time) was put on presenting the virtual model, the more the model was considered as suitable and desired for examining the road plans. However, visualisation hardly ever just speaks for itself despite what is often thought. The words accompanying and explaining the content, written or spoken, have a very high influence on the way the information is perceived (Lange, 2005). When the plan is under development, gaps that exist between grand ideas and actual land use or plans are often significant (Alfasi, 2003). Therefore, a mix of planning experience to introduce virtual model and necessary technological skills to create and enhance virtual models are needed for successful project implementation. Virtual model usually requires manual work upon creation from plans. Since plans are constantly evolving throughout the project, there is a need for applications that enable creation of virtual presentation at least semi-automatically.

General public appreciates highly virtual models. We collected feedback about the applicability. In two out of the three public hearings approximately 80% of respondents strongly agreed or completely agreed with the statement *virtual model was well suitable for examining plans.* Their opinion to use virtual models in future was also favourable. About 70% of people who answered the questionnaire considered that they are *happy to familiarize theirself with the plans with the help of virtual model in the future.* This indicates that virtual models are lucrative communication channel for experts to reach citizens. However, virtual models seem to be a rather sensitive matter. Other supplementing communication channels, 'instruments', need to be used to facilitate communication successfully. It was found out that citizens have more courage in events to discuss in smaller groups instead of a large audience. Thus, it is suggested that group work should be the main working practice whenever possible in interaction between citizens and planning team. The aim for future is to find a meaningful way to balance group dynamics with more communicative work practice.

Interestingly, the more models are used the more benefits participants seem to experience and satisfaction to event increases. Printed maps supported 'expert-expert', 'expert-citizen' and 'citizen-citizen' interaction very well, and those were used in the group sessions. Virtual models instead were used during the presentation given to the whole audience. Previous research also validates the value of face-to-face interaction, and many work practices have over the time been shaped around paper tools (Sellen & Harper 2002). The virtual model presented on the large screen was not flexible and usable enough for group work compared with paper-based interaction. People are still very much more familiar with the paper and printed maps seemed to be the natural choice for visualisation tool in the group sessions. However, our results also indicated that the plans are better understood from the virtual models than from maps. This is of course evident only when use of virtual models is prepared and managed properly.

During the last event, people's attitude towards tablet visualisation encouraged researchers. The experiment with occupants whose average age was 62 years uncovered that 70 % of the questionnaire respondents agreed *tablet application was rousing*. Based on observations, the users often experienced a wow-effect after they had learned how to navigate in the model. Thus, we suggest that presenting virtual model from a suitable mobile device, such as a tablet, alongside paper maps is a very potential way for enhancing interaction in public hearing events.

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BIM EDUCATION: A FRAMEWORK FOR KUWAIT[1]

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ABSTRACT: *Building Information Modeling (BIM) is one of the most promising advances in the design and construction industries that is significantly affecting 21st century practice activities. BIM today is becoming a common language in the AEC industry. It is increasingly being recognized as a driver for change on a global scale. Students in the Middle East and Africa are lacking behind in acquiring these new advancements. Thus, there is an accelerated need to educate the future architects and engineers in these regions about these developments. There are, however a number of major challenges for academic organizations to embrace BIM in their curricula for educating the future professionals. This research aims to address these challenges and provide a general framework for introducing BIM knowledge to Kuwait students from the recent advancement in collaborative design perspectives.*
The paper presents the current state and future strategies of integrating BIM in architectural and engineering curriculum in Kuwait institutions. It describes both a general approach and implementation plan for BIM education in Kuwait.

KEYWORDS: *Building Information Modeling (BIM), BIM Education, BIM Framework, BIM knowledge, Training, BIM curricula.*

❖ INTRODUCTION

Building Information Modeling is a Virtual Prototyping Technology and a Process considered as a revolutionary development currently reshaping the Architecture, Engineering and Construction industry. The technology element of BIM benefits industry stakeholders to visualize and investigate what is to be fabricated and constructed in a simulated environment and to identify any potential design, construction, operational or maintenance issues. The process element permits collaboration and promotes integration across various AEC disciplines. BIM is thus fundamentally changing the role of computation in building design by creating a database of the building objects to be used for all aspects of the building from design to construction and beyond. Many researchers reported that the collaborative use of BIM by the AEC industry indicate that collective BIM process benefits in delivering projects with resources, higher quality, and greater customer satisfaction (Eastman et al. 2011; Jäväjä et. al. 2013).
Within the nucleus of the evolution of BIM is education. Contrary to the evolution, there are, however many issues currently facing the complete adoption or integration of BIM in architecture and engineering education in the Middle East and Africa. This is attributed to the fact that BIM is perceived by academia as a professional advancement in project design, development, delivery, and operation that lacks the theoretical construct of traditional courses, such as structural analysis or environmental technology. Furthermore, most academic institutions are struggling with BIM adoption because to date, there is no common understanding of what skills are needed in the industry, nor of what should be the content, principles, and methods of education in these fields that include BIM (Sacks et al., 2013).
Without the proper incorporation of BIM as a valid discipline and an area for scholarship, many faculties who strive for advancement may not find the time or energy to educate themselves or integrate BIM in their teaching or research. In the US and other parts of world AEC schools have implemented a variety of pedagogical methods for introducing BIM into their curriculums. They range from using BIM in architectural studio, sustainable design, and construction management to Civil Engineering (Önür, 2009; Sharag-Eldin and Nawari., 2010;

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Barison et al., 2010; Sacks et al., 2010; Wong et al., 2011). For instance, Önür and Sharag-Eldin & Nawari described how BIM is integrated into architectural curriculum. Sacks et al. (2010) introduced BIM as an integral part of freshman year civil engineering education

Reviewing BIM curricula in the US and other academic institutions shows that varying approaches have been undertaken to integrate BIM into their curricula. However, there is no commonly agreed upon method for teaching BIM in AEC programs (Barison et al. 2010). Most schools offer BIM in only one to two different courses. Many courses limit their coverage to a short period (one to two weeks) (Becerik-Gerber et al. 2011). Quite often, the BIM course is limited to a single discipline in 90% of the cases (Barison et al. 2010). Joannides et al. (2012) surveyed a number of schools in the United States about implementing BIM courses in architecture and construction schools. Their results indicated that most architecture and construction schools either have an interest in or have already implemented BIM into their curriculum. In the majority of the schools they perceived BIM as important to the industry; and planned to fully integrate BIM into their curriculum (Joannides et al., 2012).

The majority of schools introduce BIM on a basic level by teaching a specific software tool, limiting their perspective on BIM to viewing it simply as another CAD productivity enhancing tool for creating 2D and 3D drawings (Sacks et al. 2013). However, BIM by nature goes far beyond digital drafting (Eastman et al. 2011). A comprehensive literature review on the subject can be found in the work of Barison et al. (2010) and Sacks et al. (2013). Their main findings indicated that schools wishing to implement BIM in their curriculum are likely to face many difficulties. The greatest challenge facing theses schools is promoting integration between different areas of the curriculum using BIM and to find programs from other departments or units that are willing to promote collaboration.

Since BIM is quite different from traditional CAD, it does require new ways of thinking about the pedagogical aspects. For example, BIM facilitates collaboration and teamwork across disciplines that must be incorporated into teaching BIM courses. Furthermore, BIM provides rich visualization of building elements and parametric modeling of behavior, which can enhance students' learning experience in virtual construction such as understanding how building elements fit together just as they must on a physical site (Eastman et al. 2011).

This paper describes the current state of the art in BIM education in Kuwait Universities and institutions, and establishes an educational framework for introducing BIM courses in Kuwait. It focuses on defining objectives and content requirements for various levels of courses in higher education.

CURRENT STATE

The current state of BIM education in Kuwait was established by examining the syllabi of architecture and civil engineering courses at different institutions. The status of BIM adoption in the AEC industry in Kuwait according to the authors' conducted survey is very slow and limited to isolated large projects, notwithstanding the industry as a whole is growing. It seems education is going to take the lead in bringing BIM awareness and adoption in Kuwait construction industry.

The section report on the prevailing undergraduate and graduate courses devoted to the study of building information modeling (BIM) and discusses constraints and needs of BIM curricula in Kuwait.

Kuwait University

The Department of Architecture at Kuwait University has introduced BIM tools to their students during the academic year of 2012-2013. BIM tools were first used in the Structural Analysis class during the summer course of that year. Each student had to virtually model the structural components of an existing residential house in Kuwait. The exercise aimed at introducing the structural BIM to students as well as understanding how to read structural plans. The exercise also targeted the understanding of the sizes and the proportions of different structural elements according to their functions. Furthermore, students were asked to use BIM authoring tool to produce the concrete bill of quantity for each type of component.

BIM tools had also been offered to students in the Computer Applications in Architecture class alongside the predominant AutoCAD® software. BIM was introduced to replace other 3-D software programs such as 3ds Max®. In addition, BIM tools were offered in one of the Design Studio courses during the same year. Mostly students learned BIM tools on their own to produce their final studio projects.

BIM as standalone class was only offered in the 2013-2014 academic year as a technical elective course for students with more 60 credit hours in the Department of Architecture. It was offered as lectures based and labs. Throughout the lectures, students were informed of the advantages of BIM for the lifecycle of a project with more emphasis to the design process and workflow. The syllabus covers BIM concept, the evolution of BIM and its advantages, collaboration capabilities, and the advantages of the Integrated Project Delivery (IPD) and how BIM plays an important role in the early design phases of any project. In the lab portion of the course, Autodesk BIM curriculum was assigned to students. The curriculum introduces variety of topics with video tutorials. Students learn the basic functions from the tutorials and apply them in the preset exercises. One of the course projects was to create a library based on the available materials and finishes in the Kuwaiti market. In addition, and due to the technical nature of the course, students had to construct the architectural model of an existing residential house in Kuwait. Students were asked to apply design changes to the houses' facades to enhance their aesthetic and functional features. Additionally, some exercises deal with solar study illustrating the shadow casts of neighboring houses during different time of day during different seasons, subsequently redesigning the facades accordingly. Another assignment was to analyze the living spaces based on their functions and level of privacy using the area schedule tools available in BIM. The final requirement was to generate a Bill of Quantity (BOQ) for the entire house less the structural elements.

The application of BIM was also encouraged by seminars provided by the program vendors as well as workshops presented by the students bodies at the Architecture Department.

In higher design studio classes, students have the choice of using any digital tools to execute their design projects. Some students choose BIM only for its 3-D drawing advantages. BIM has not yet been fully utilized beyond the 3-D capabilities in design studio courses. In a shy effort, some students use the BIM tools for the Working Drawings class offered by the Architecture Department. Others hesitate due to the detailed nature of the projects in this course because of their limited exposure and knowledge of the BIM tools. Others choose to use BIM for the general design of the floor plans, elevations and sections and for detailing they use the AutoCAD® software program. Nevertheless, all students turn to manual calculations for the preparation of the BOQ in that class.

Despite all the efforts of advocating BIM to students, the experience is still young and based on individual efforts from two professors only. The Architecture Department and College of Engineering are yet to join in mandating BIM into their curricula.

So far, the Department of Architecture is the only department offering BIM tools to their students. Other departments such as Civil, Mechanical, and Electrical Engineering are still in the process of investigating the value of incorporating BIM into their curriculums.

Other Institutions

Kuwait University (KU) is the only public university in the country. Other private universities and colleges are available including the American University of Kuwait (AUK), the Gulf University for Science and Technology (GUST), the American University of the Middle East (AUM), the Arab Open University (AOU) – Kuwait, the Australian College of Kuwait (ACK), the American College of the Middle East (ACM), Box Hill College Kuwait - Higher Education for Women (BHCK), and the Kuwait-Maastricht Business School (KMBS). Table 1 summarizes the different engineering and architectural programs offered by universities and institutions in Kuwait ranging from the 2-year Diploma in engineering to the Masters programs.

Programs / Institution	Diploma Civil Engr.	B.Sc. Architecture	B.Sc. Civil Engr.	B.Sc.Engr.(non Civil)	M.Sc. Architecture	M.Sc. Civil Engr.	M.Sc. Engr. (non Civil)
KU	-	Yes	Yes	Yes	Yes	Yes	Yes
AUK	-	-	-	Yes	-	-	-
AUM	-	-	-	Yes	-	-	-
ACM	-	-	-	Yes	-	-	-
ACK	Yes	-	Yes	-	-	-	-
PAAET	Yes	-	-	-	-	-	-
GUST	-	-	-	-	-	-	-
AOU	-	-	-	-	-	-	-
BHCK	-	-	-	-	-	-	-
KMBS	-	-	-	-	-	-	-

Table 1. Kuwait Academic Institutions Programs

Kuwait University is the only institution in Kuwait that offers a degree in Architecture. The College of Engineering at KU offers a wide variety of Engineering Degrees including Civil Engineering. On the other hand, three private institutions also offer engineering degrees. The AUM offers engineering degrees limited to Industrial and Computer Engineering. The ACM also offers an Electrical Engineering Technology Program. The ACK offers two degrees under the Department of Civil Engineering. The first degree is a 2-year Engineering Diploma of Civil Construction Design. In this degree, “Students will be taught engineering drafting standards and be given exposure to CAD packages such as AutoCAD and surveying.” along with other Civil Engineering principles. The second degree is a Bachelor of Engineering Technology (Civil). The degree is licensed by the Central Queensland University, Australia (CQU). This second degree requires 2 additional years after the successful completion of the first degree.

The other public institution in Kuwait is the Public Authority of Applied Education and Training (PAAET). It offers a wide range of degrees including a 2-year degree of Civil Engineering offered under the Civil Engineering Department at the College of Technological Studies. Students have the option of joining any of the three sub-specialties Building Technology, Highways and Roads or Surveying. AutoCAD® software is the only

drafting program taught to students. Thus, none of these schools offer BIM courses.
In summary, Kuwait University through its Architecture Department is the only educational institution in Kuwait that has started integrating BIM tools into their curricula.

PROPOSED FRAMEWORK AND GUIDELINES

The architecture, engineering and construction industry is embracing BIM technology quickly, incorporating new opportunities to streamline the design, construction and operation processes and to save time, money and other resources. The academic institutions should passage more deliberately and thoughtfully to incorporate BIM technology and process.

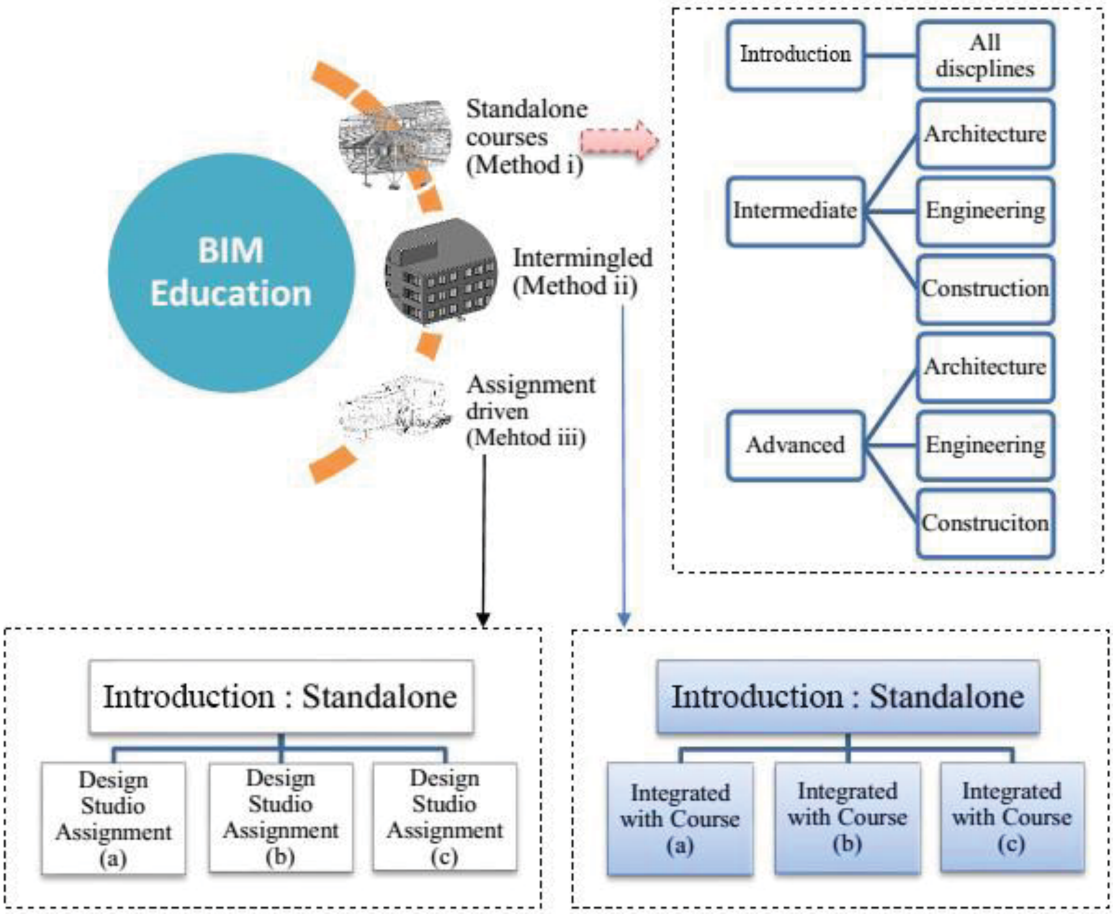

Fig.1: Schema of the proposed framework for BIM education in Kuwait

There are several education techniques that can be employed for introducing BIM education in AEC programs. However, three main methods are considered critical for Kuwait: (i) Standalone BIM courses; (ii) BIM intermingled with existing courses; and (iii) BIM integrated in students' assignments only. Figure 1 depicts the schema for the proposed framework for BIM education in Kuwait.
As for the stand alone courses, three courses with different levels are proposed. An introductory course that is required for all AEC students. The specific learning objectives and curricula outline along with evaluation criteria are depicted in Table 2. Two additional courses are recommended to be tailored towards each specific discipline as shown in Figure 1. These courses cover intermediate and advanced topic for higher level students. For example, Table 2 depicts goals and contents outline for the intermediate and advanced standalone courses for structural engineering curriculum.

Table 2. BIM Introductory course

Objectives	Content outlines	Evaluation	Outcomes
Provide fundamentals of BIM technology and process in order to understand parametric, object-oriented and geometric modeling to support design, engineering analysis and performance simulation, construction planning and design communication for facility construction.	- BIM concepts and History of CAD - Parametric and object-oriented modeling - BIM authoring tools, central databases and information repositories. - Methods to store and share information. - Develop, coordinate, and communicate BIM model. - Modeling with standard libraries of elements. - Creating and modeling with custom building elements. - Conceptual Massing and solid modeling.	- Weekly homework assignments. - Two to three projects aiming to assess knowledge conveyed. - Research paper focusing on the emerging technology and process of BIM in the industry.	- Understand basic BIM concepts. - Ability to distinguish between BIM and traditional CAD process. - Have a basic working knowledge of BIM tools. - Ability to use the learned BIM skills and tools in design projects.

After the introductory standalone course, BIM can be also taught in conjunction with other courses. For example, in Material and Methods classes BIM tools can be utilized to address and answer homework problems related to wall sections, material selections and definitions, as well as elevations and sections details (Method (ii)). Another module is the implementation of BIM tools for a specific project assignment such as in an architectural studio courses (Method (iii)). Details about method (ii) and (iii) will be addressed in a separate paper as their requirements and pedagogical process are different than in method (i).

Table 3. BIM intermediate course for structural engineering curriculum

Objectives	Content outlines	Evaluation
To provide principal of structural modeling, digital design and analysis of structures.	- Structural Planning - Structural BIM using one of BIM authoring tools. - Modeling Columns, beams, floor slabs, roof decks, walls, framing, foundations, and rebars. - Examples: Concrete Buildings, Steel Buildings, Wood Framed Buildings, Hybrid Buildings. - Sheets and construction documents - Creation of customized library of structural elements.	- Weekly lab assignments - Two to three term projects

Table 4. BIM advanced course for structural engineering curriculum

Objectives	Content outlines	Evaluation
Emphasizing cross-disciplinary collaboration and provide students with means through which integrative pedagogical goals are attained through BIM.	- Visualization and renderings for aesthetic assessment - Generate multiple design alternatives and project phases - Model sharing and collaboration: internal and external sharing - Management of information flows - Perform structural analysis - Productivity, Interoperability - Check code compliance - Clash detection - Automated generation of drawings and construction documents - Perform discrete event simulation - Integrated practice: contractual and legal aspects of BIM implementation; BIM standardization	- Weekly lab assignments - Two to three term projects

A plan for implementation and testing of this framework is underway at the School of Architecture, Kuwait University for the spring 2015 semester.

CONCLUSION

Teaching BIM in general cannot be approached in a fashion similar to that adopted for computer-aided drafting (CAD) in architecture and engineering programs. BIM is not only a new technology tool for generating design documents but also a comprehensive process for information management and analysis that academia in the Middle-East and Africa must recognize and incorporate into their curriculums.

The paper addresses the current state of BIM education in Kuwait Universities and institutions, and establishes an educational framework for introducing BIM courses in Kuwait. The inherent goal however, is to make this framework an integral part of the AEC education in Kuwait while maintaining the rigor and the theoretical constructs of academic exercises.

The research focuses on defining objectives and content requirements for various levels of courses in higher education. The framework recognizes the unique characteristics of BIM and provide a systematic and holistic approach to BIM education in Kuwait. The proposed framework outlines the different approaches for teaching BIM, namely standalone courses, BIM interlaced with other courses, and project-driven BIM. This work focuses on the standalone approach and describes objectives, curriculum content and evaluation for the standalone approach. An introductory standalone course is defined as a required course for architecture, engineering, and construction students. This course focuses directly on the fundamentals of building information management, computer modeling for representing building elements, and on the technological aspects of BIM tools. Intermediate courses are proposed to incorporate BIM aspects as a part of the core architectural and engineering courses, concentrating on teaching BIM for specific discipline, such as for architectural design, construction management and planning, structural engineering, and MEP engineering. At the higher levels, advanced BIM courses are proposed to emphasis collaboration, team work, and cross-discipline activates as well as management of BIM projects across organizations.

The proposed BIM framework provides a learning build environment that integrates design and construction insights in a highly collaborative and interoperable format. With this proposed framework for incorporating building information modeling into the curriculum in Kuwait or other Middle-Eastern and African institutions, one would expect the academia to have a great opportunity to impact and advance the entire AEC industry in these regions.

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MAPPING OF BUILDING INFORMATION MODELING BUSINESS PROCESS MODEL AND RELATED ISSUES IN BOTH THE SCHEMATIC DESIGN AND DESIGN DEVELOPMENT PHASES1

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ABSTRACT: Building information modeling (BIM) can be defined as the core management of information and the complex relationships between the social and technical resources that represent the complexity, collaboration, and interrelationships of today's organizations and environments. The focus of BIM is on managing projects to get the right information to the right place in the proper time frame, but BIM, like many other products in the project management software industry, currently faces significant issues that prevent its widespread use. There arises the need for businesses to assess and rethink their existing processes, communication mechanisms and information flow strategies in order to fully avail themselves of the opportunities that BIM has to offer.
This paper focuses on mapping the existing issues related to BIM workflow in mid-size firm in USA, in order to identify both related communication and information constraints that are facing BIM users during the Schematic Design (S.D) and Design Development (D.D) phases, the research first attempted to map the “As-is” BIM related process model using Business Process Model and Notation (BPMN) technique, and then identify the issues associated with this model.

KEYWORDS: BUILDING INFORMATION MODELING (BIM), BUSINESS PROCESS MODELING (BPM), SCHEMATIC DESIGN (S.D), DESIGN DEVELOPMENT (D.D)

❖ INTRODUCTION

Today, there is little doubt that Building Information Modeling (BIM) is a new technology that is reshaping the building industry. BIM has emerged as a useful tool for architects, engineers, and contractors in the delivery of new constructions. BIM is an innovative tool that most design and construction professionals do not currently use on a regular basis. According to the Smart Market report, in 2008, architects were the most frequent BIM users with 54% usage (McGraw-Hill 2008). However, as those professionals increase their understanding of BIM and its capabilities, BIM will likely become a part of common design and construction practices. On the other hand, BIM, like many other products in the project management software industry, currently faces significant issues and obstacles that prevent its widespread use. These issues include inappropriate adaptation strategies, old management and organizational structures, and slow software development (McGraw-Hill 2008). There arises the need for businesses to assess and rethink their existing processes, communication mechanisms and information flow strategies in order to fully avail themselves of the opportunities that BIM has to offer. This may involve the means to smoothly shift from existing CAD platforms, and how to find the precise changes that can prompt architectural offices to improve their existing business processes, and develop strategies that are flexible enough to incorporate BIM as it evolves.
Based on these requirements, this paper focuses on the need of mapping the BIM implementation challenges that are currently exist in mid-sized architectural firms as they relate to how information flows, BIM related activities and the existing business processes model. For this, two case studies and several interviews were conducted. The case studies and the interviews findings helped to develop the existing business model and to identify challenges associated with BIM implementation, and the potential areas for improvement, especially those ineffective processes at the

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departmental boundaries. The focus of this paper will be limited to the challenges that are facing BIM implementation during the Schematic Design (S.D) and Design Development (D.D) phases.

BIM DOMAINS

By using the 'conceptual clustering' of observable activities and the discovering of roles and interactions in the AEC industry, Michalski has identified three main domains for BIM where information is being exchanged and developed rapidly between these domains: Technology, Process and Policy (Underwood and Isikdag, 2010) (Michalski, 1987). Each of these domains has its players, requirements and deliverables. Those players can be individuals, teams, organizations or other groupings (Figure 1) (Underwood and Isikdag, 2010, p.66). A complete BIM process model is when these three BIM domains interact within the AECO industry, this forms the whole BIM process model.

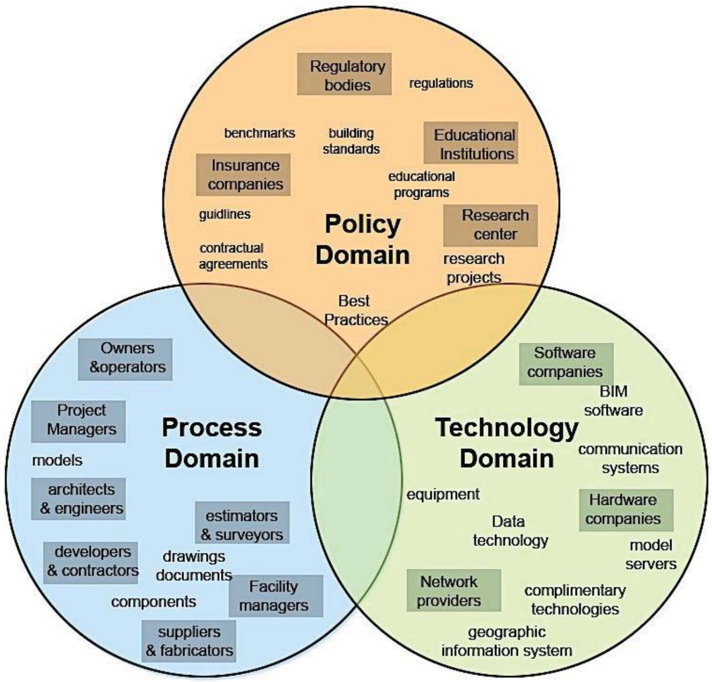

Figure 1 The three main domains of Building Information Modeling (BIM)

Technology Domain

The BIM "Technology" domain includes organizations, and software and hardware vendors that focus on the technical aspects of BIM use; the players of this domain could help to directly and indirectly enhance efficiency and profitability of BIM related procedures by developing software, hardware, equipment and networking systems.

Policy Domain

The "Policy" domain contains a group of players from insurance companies, universities and research centers, etc. who focus on preparing practitioners, delivering research, distributing benefits, allocating risks and minimizing conflicts within the AEC industry (Underwood and Isikdag 2010). Although the roles of this group don't appear to be clearly articulated in the current BIM modeling procedures, these roles are vitally important because they lead to changes in the AEC industry.

Process Domain

The last domain, which is the main focus of this research, is the "Process" domain. This domain includes BIM members who handle BIM documents and information. This group includes facility managers, owners, engineers, contractors, architects, etc. This information can be used for ownership and operations of buildings or construction operations (Underwood and Isikdag, 2010, p.66).

Although the Policy domain has a major impact on BIM workflow, making changes to this domain requires involvement of stakeholders outside of the project team, which is not a focus for this research. Thus, this paper will focus on the other two domains, Process and Technology, and the relation between the business process modeling/reengineering and these two BIM domains (Figure 1). Based on these two domains and the modeling approaches, the interviews questions and case studies criteria have been formulated.

BUSINESS PROCESS MODELING (BPM)

Business Process Model (BPM) is commonly a diagram representing a sequence of activities that shows sequential events, actions and links or connection points. Reengineering Business Process (BPR) focuses on a specific change at any level of organizational structure of the whole management system. Although the Business Process Modeling has different approaches, the main approaches are the Business Process Model and Notation (BPMN), the Unified Modeling Language (UML) and Integrated Definition (IDEF) modeling. According to Dana Smith, the most common approaches that are being used in the AEC industry are the BPMN and IDEF, and because some of IDEF modeling technique limitations that have been discovered during the research time, this paper will focus on the BPMN technique.

RESEARCH METHODS AND DATA COLLECTION

The researcher adopts a qualitative method, as it is suitable for the goals and objectives for this research. The qualitative approach that has been used in this research is the Grounded Theory, which depends upon inductive reasoning to generate theories or models from empirical data. Also, because there are very few existing business process models for mid-size architectural firms, thus, the situational interpretive aspect of the Grounded Theory method seemed appropriate for this research. Moreover, Grounded Theory provides guidelines for the collection of data that are applicable for the research when there is little pre-knowledge of these data, which is the case in this study. Interviews and two case studies have been used through two phases of data collection, which can be summarized as the following.

First phase – Data Collected to Identify BIM issues

During the first phase of this investigation (Jan 2010- Nov 2011), the researcher conducted several interviews (semi structured interviews) to collect data that could help identify BIM related issues, and the links between them and the existing BIM related business process model.

Second Phase – Data Collected to map the “As-is” workflow

Two case studies were conducted to map BIM related process modes, however the duration of the case studies was not long enough to develop a business map for the entire BIM related activities. Thus there was a need for collecting more data using interviews to develop a complete preliminary “As-is” business process model thus another round of interviews (structured interviews) was conducted (Jan 2011- Oct 2011), where interviewees were asked to recall their roles and activities inside the targeted firms, as well as to describe the routes of information flow and how decisions are made.

MODELING AS-IS WORKFLOW USING THE BPMN TECHNIQUE

In this paper, the BIM related process model has been generated using the BPMN method in order to describe the sequence of activities and the flow of information in more details. The BPMN model was distributed to a sample of BIM stakeholders upon their requests for more information about BIM procedures and also to compare BIM functions from one firm to another. At this point, the researcher had to go into each business component to explain in detail, activities, decisions, communication types, 'performed by whom', and the flow of information. This helped the researcher to get more specific comments and feedback concerning how BIM stakeholders see the existing model and also to identify the problems, which limit a more complete BIM implementation.

The BPMN model presented here is composed of three levels (subjected firm, model process-component and activity/tasks levels), the model displays different kinds of decisions which are taken by BIM members, plus the exchange of information between them. The generated workflow model is a general and flexible template that not only represents one mid-sized firm in the field of study, but also, according to interviewees' feedback, reflects a broad number of mid-sized firms in the USA with similar BIM practices.

BIM "As-is" workflow – Schematic Design Phase

With the aid of different data resources, including; researcher's notes, diagrams and memos that were gathered during the case studies, in addition to the interviews that were conducted to understand BIM activities and tasks in the Schematic Design phase, the researcher was able to map BIM workflow as the following.

1. The workflow usually starts once the client initiates the need for the project. Usually, the client has preconceived knowledge of the project's purpose and what benefits should be achieved.
2. Then the process inside mid-size firm starts with preparation of the project brief and the establishment of stakeholders' involvement which is followed by the appointed BIM manager who starts an overall process review, that includes planning, managing project documents, and preparation of the project brief.

After preparing the project brief, the next step is the "bubble diagram", followed by the start of schematic sketching that is requested by the project manager, who typically assigns someone to get the proposal/proposals schematically into Sketch-Up. At this point the model typically only represents the project proportion and massing.

3. Once the Sketch-up model reaches the final stage of the conceptual design, the architect usually has a meeting with the client to agree upon the layout.
4. At the same time the project manager assigns another person with the task of laying it out schematically on Revit (Pre-Schematic Drawings). Once the model is transferred to Revit, the process goes back and forth between the appointed BIM manager and the architectural team to develop the concept and basic framework for the design of the project.
5. The model will also be developed to provide "preliminary LEED documents".
6. The next step is to prepare the preliminary feasibility study, which should be reviewed and approved later by the BIM manager.
7. If the preliminary feasibility study is accepted, the execution plan and design management report (including design process, budget and schedule, communication protocols as well as roles and responsibilities of the various parties) will be presented to the client for the "Schematic Design Approval".
8. Then, if the client approves these documents, they can proceed to the next phase of the project.

BIM "As-is" workflow – Design Development phase

The Design Development phase involves more inputs from different disciplines. Typically, these inputs are not found in the Schematic Design phase and may include the development of architectural drawings, structural drawings, building services drawings (MEP+HVAC), fabrication drawings and cost estimation. Thus, this phase is more interlinked than the Schematic Design phase and its process model tries to represent dependencies and overall information flow from different disciplines. The existing model for this phase can be summarized in the following steps:

1. After the approval of the schematic design, the architectural team develops the BIM model to illustrate more in-depth aspects of the proposed design; they also verify that the proposed design complies with US building codes and LEED project compliance.
2. After this revision, the project stakeholders usually have a "kick off meeting", in which they identify the project keys, such as; each stakeholder's responsibility, scopes, standards, who's modeling what, levels of detail, push for extra time and fee if it's more than you've budgeted, etc.
3. Typical to the case study, and in the "best case scenario", the appointed BIM manager sends the BIM model to the MEP team so they simultaneously start MEP and HVAC design earlier at the beginning of the design development phase. Thus, the MEP team starts the development and expansion of the mechanical Schematic Design documents and criteria for lighting, electrical and communications systems that have been suggested by the architectural team.
4. Upon the approval of the MEP and HVAC feasibility study, the BIM manager sends the model to the structural team.
5. After making the required changes, the last step on the structural design is to prepare the feasibility study. Once the feasibility study is accepted, the BIM manager will review the whole business process and project documents. At this time, the architectural team works on landscape design and documentation services as well as the development of outline specifications or materials lists to establish the final scope and preliminary details for on-site and off-site civil

engineering work and landscaping work.

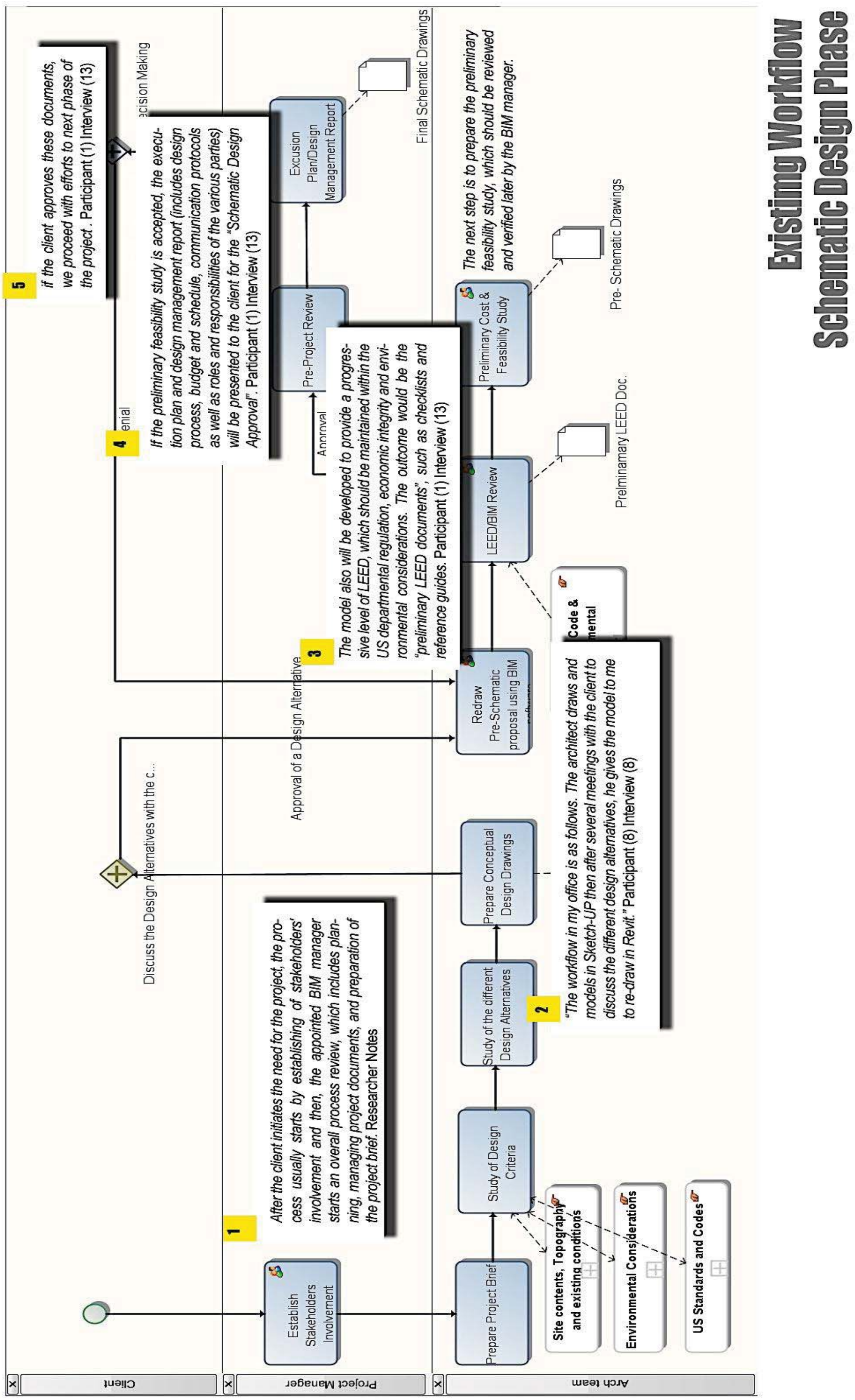

Figure 2 Schematic Design Phase- BIM workflow

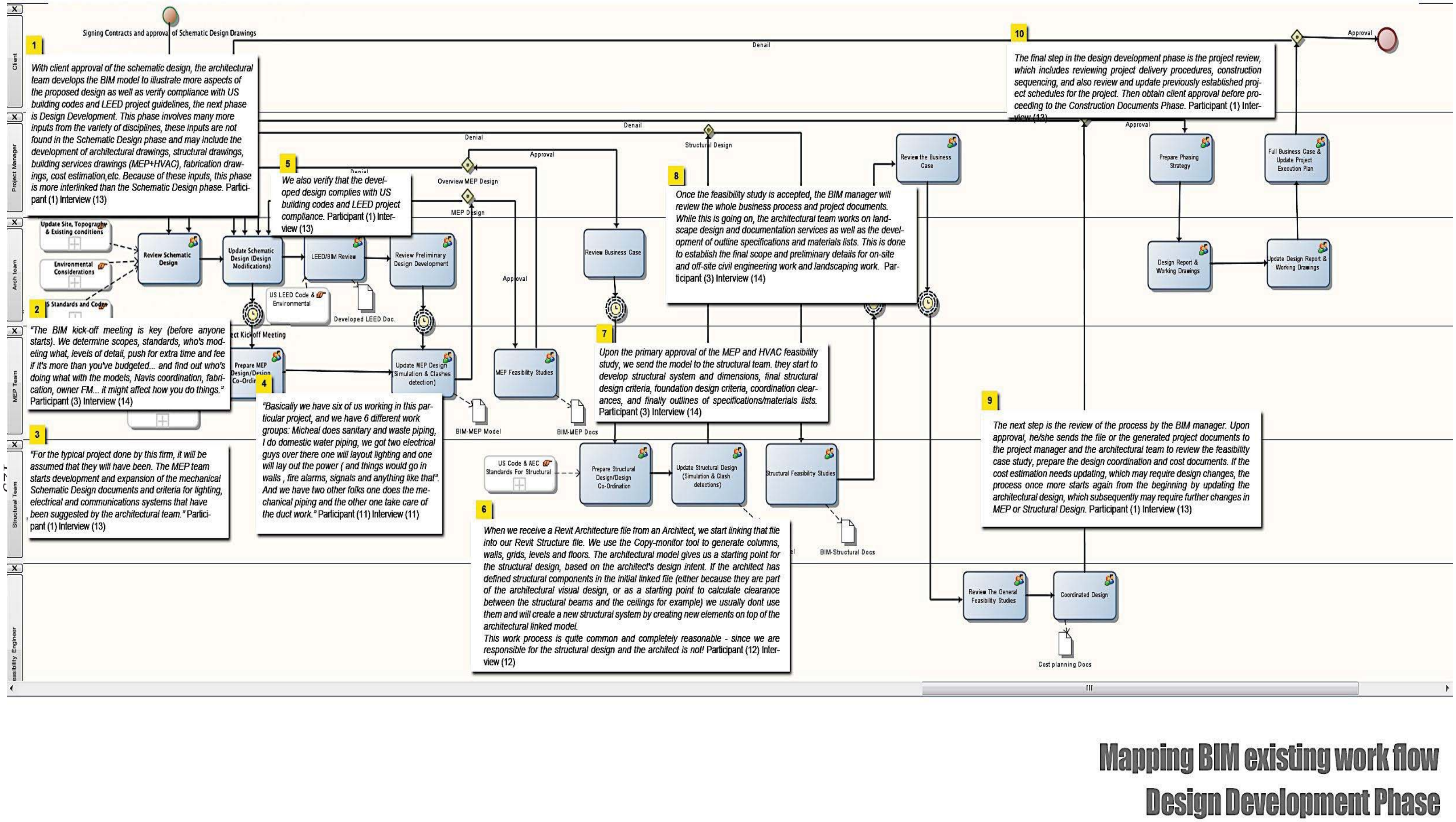

Figure 3 Design Development Phase- BIM workflow

6. The next step is the review of the process by the BIM manager. Upon approval, he/she sends the BIM model or the generated project documents to the project manager and the architectural team to review the feasibility case study, prepare the design coordination strategy and cost documents. If the cost estimation needs updating, which may require design changes, the process once more starts again from the beginning by updating the architectural design, which subsequently may require further changes in MEP or Structural Design.

7. The final step in the design development phase is the project review, which includes reviewing project delivery procedures, construction sequencing, and also review and update previously established schedules for the project. Then client approval is obtained before proceeding to the Construction Documents Phase. Figure 3 summarizes the design development workflow.

BIM RELATED ISSUES- SCHEMATIC DESIGN PHASE

In the following section, the researcher presents his research findings from issues that limit the optimum implementation of BIM during the Schematic Design phase. Initially, the issues were classified into two domains, the first being the “Technology domain” the second is the “Process domain”.

Technology domain issues - Schematic Design Phase

Although the researcher was not expecting to find any technology related domain issues in the Schematic Design phase, because BIM is less frequently used in this phase, but contrary to expectation, one major problem was revealed through the first case study. It has been revealed to the researcher that BIM and early stage design applications are not formatted for easy integration, which results in BIM users often redrawing the entire project after reaching the final stage of conceptual design. The researcher has found that because drawings have to be initially presented using design software such as Sketch-up, and then redraw the whole project using BIM software, this usually causes a redundancy in workflow, in addition to loss of time. Unfortunately, this is the standard workflow for many mid-sized firms in the USA (Figure 4).

Process Domain related issues - Schematic Design Phase

The first case study, in addition to the interviews, revealed two major Process domain issues. First was the lack of contractor involvement in the S.D phase and second the similarity of the existing BIM workflow with old CAD workflow. Through the first case study it was shown that the contractor had little, if any, involvement in the Schematic Design phase. The reason might be due to the Design-Bid-Build (DBB) method that was used for both case studies projects. Although there are a number of construction project delivery methods in addition to the traditional and most common DBB.

BIM RELATED ISSUES- DESIGN DEVELOPMENT PHASE

It is important to mention that generally during the S.D and D.D phases there is poor communication between team members. Some participants mentioned that there is a lack of communication between different BIM users, which results in loss of time and duplicated effort. In the following both Technology and Process domain issues that have been found through case studies are presented. The process domain issues in the Design Development phase can be classified as follows: lack of contractor involvement, routing of information, lack of a BIM central model, and sequence of activities.

Lack of contractor involvement

Similar to the Schematic design phase, mapping the workflow as it relates to the use of BIM in the D.D phase revealed the lack of the contractor involvement. The researcher questioned one of the interviewees about what could be the process scenario due to the lack of contractor involvement, he answered; “because there was no contractor since the beginning of the project, the model usually has a certain amount of information that may be too much or too little; then we started to build into the model, whether these information is accurate or not but we have to add it anyway. The problem occurs once the contractor gets involved and requests more information (RFI’s), someone has to go back to plug-in more data or to check it. When these requests come in at the last minute this may cause a lot of extra work.”

Lack of BIM central model

The lack of BIM central model and the difficult routing of information, are related issues. The second case study showed that because there wasn’t a BIM central model to act as a central communication/information hub, information routing was difficult. In the next section the concept of a central BIM model is presented in terms of how this could affect the flow of information. To explain the importance of the “central model” further, Olcay Çetiner states “The idea is that if you want to interconnect a large number of nodes, you can reduce the number of interfaces by creating a central node. The nodes can be models of different applications, domains, or disciplines. The central node can be called the central model, or core model, or kernel model, etc.” (Underwood and Isikdag 2010).

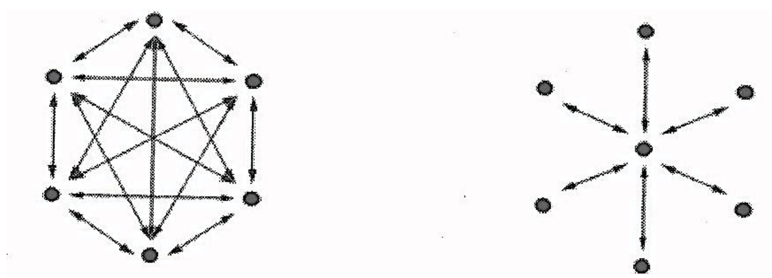

Figure 5 Communication Nodes (Underwood and Isikdag 2010)

Without a central node (left picture- Figure 5) the number of interfaces between n nodes is [n (n-1)], whereas the number of interfaces with a central node (right image) is reduced to 2n. Unfortunately, the “central model” scenario is not implemented in many mid-size firms. This is due to the situation that for many of these firms their MEP or Structural engineering teams are remotely located. Thus, the BIM stakeholders share the model through separate files (Similar to CAD systems) and not as a central model (for example: one BIM file for MEP data, one for the structural data, and one for the architectural team).

Routing of information

The researcher observed that because of the lack of a central BIM model, there is no direct communication between BIM users, which subsequently affects the flow of information by increasing the communication routes. It was observed that BIM mangers in both firms have control of everything regarding BIM data and documents. All BIM users for both firms have to send information through a FTP server to be verified and approved by the BIM mangers before sending it to other BIM users, or they may contact him/her if they need help with any missing information. With this structure, the BIM manager contacts the other consultants or BIM users, while the BIM users do not have direct communication between each other. The main BIM model is updated to the FTP server once a week, usually Fridays. Because of poor communication with the central BIM model, and the resulting longer route for information flow that is common in mid-size firms, it has been found that for this situation BIM users are losing time.

Sequence of activities

It was found that many BIM related activities are linear, rather than parallel activities. This usually causes redundancy in the "As-is" workflow, because once a new BIM group of activities is added, the new BIM users, who are responsible for this group of activities, have to rebuild/modify/update the BIM model to fulfill their needs.

Technology domain issues- Lack of interoperability

Participants in the interviews indicated that the lack of interoperability is a significant constraint to achieving an efficient workflow between architectural, structural, MEP and other building services design disciplines. Progress is being made in this area with the development of open standards such as IFC (Industry Foundation Classes) and CIS/2, yet the researcher discovered that these standards have some limitations that prevent BIM users from using them in their firms.

Based on numerous examples of interoperability issues identified in both firms of case studies, it seems likely that any new BIM user has to incorporate his/her own BIM data into his/her model, and should expect to deal with interoperability issues by redrawing or editing the model, which consumes time for updating the model. Figure 7 identifies the areas of redundant activities caused by the redrawing/editing or embedding of new information into BIM models, which subsequently consumes more time to solve interoperability issues on the "As-is" BIM model.

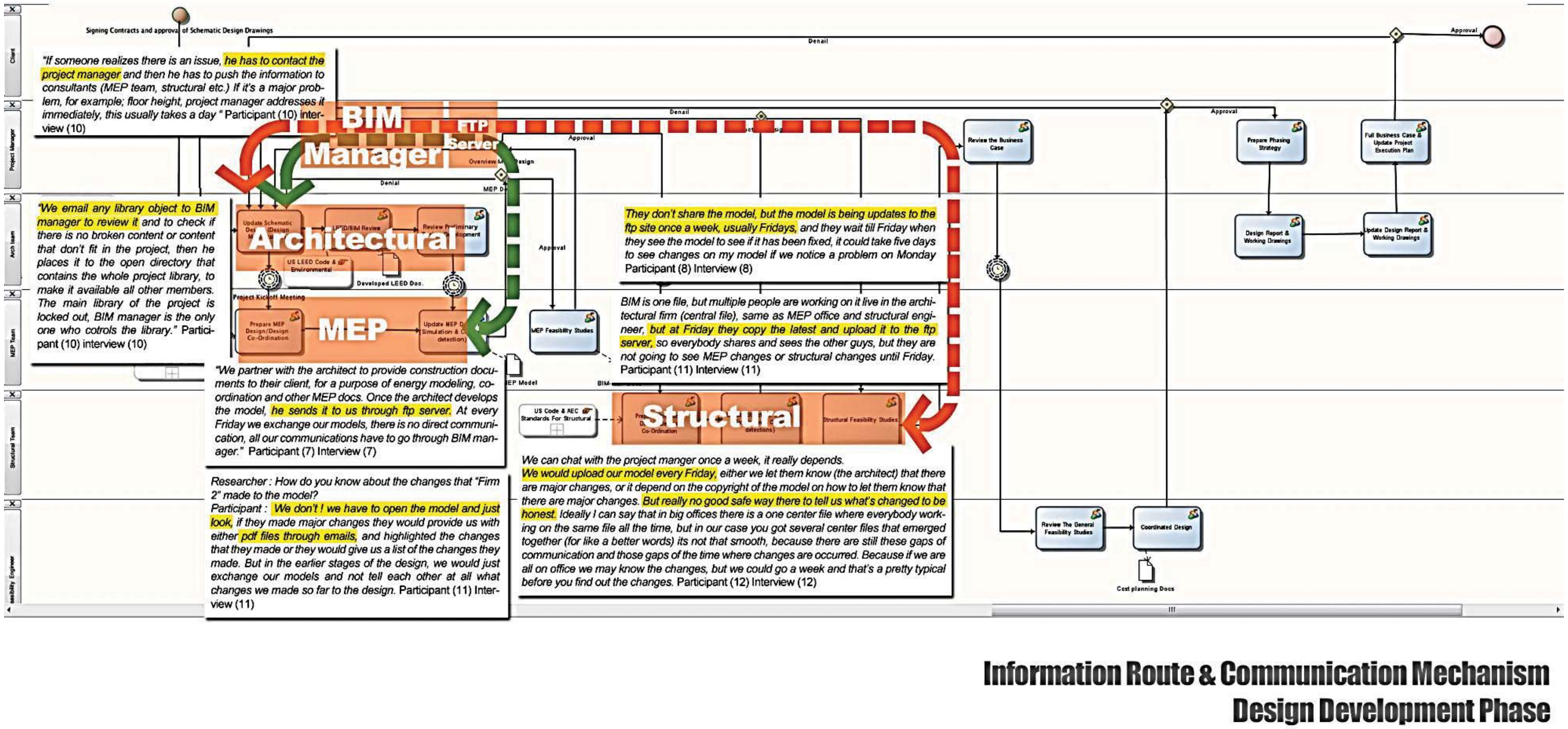

Figure 6 Information route and communication mechanism – Design Development Phase

SUMMARY

This paper is a part of an ongoing research that focuses on mapping the challenges that face BIM implementation in mid-size firms in USA during the Schematic Design (S.D) and Design Development (D.D) phases. To meet this objective, the research first attempted to map the “As-is” BIM related business process model, and identify the issues associated with these two domains. As it was previously established, there are various methodological strategies that could be utilized for obtaining data when applying a qualitative approach. In this research the case study and interview tactics were used. Through interpretation of the data collected through these tactics, it was found that BIM is facing different types of issues. For example, direct communication challenges, missing of a “central model”, poor flow of information, lack of control for data feed, lack of interoperability, etc. The research findings were triangulated with feedback from BIM members not in the first round of interviews. Theoretical saturation is reached when no new relevant data emerges and an initial concept about the categories of tasks/activities is well developed. Narrative scenarios, interviews transcripts, case studies, in addition to the other types of data helped to form an initial workflow model.

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ENHANCING SPATIAL AND TEMPORAL COGNITIVE ABILITY IN CONSTRUCTION EDUCATION THROUGH AUGMENTED REALITY AND ARTIFICIAL VISUALIZATIONS[1]

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ABSTRACT: *It is essential to fully develop the learning abilities of the future industry workforce to effectively solve construction problems. The ability of Construction Management (CM) students to solve problems is hindered by their lack of exposure to construction processes on the job-site, which results in the students' lack of understanding of the dynamic complex spatial constraints (e.g., how construction products are related to one another in particular contextual space) and the temporal constraints (e.g., the dependencies for coordinating subcontractors' processes). As spatial-temporal constraint (STC) problems pervade projects during the construction phase, a full understanding of these STC problems is critical to enable CM students to improve productivity levels through improved problem solving skills.*

This research uses Augmented Reality Technology (ART) and a layer of artificial visualizations to simulate the environmental context and spatial temporal constraints. The superimposition of images serves as an instructional mechanism to virtually incorporate jobsite experiences. The assumption is that the enhancement of spatial-temporal constraints enables learners to visualize context and hidden processes. It is anticipated that the results of this research will show a significant improvement of the perception of the reality through the combination of two layers (the real environment and the computer-generated information) including the learners' ability to understand the complexity of construction products (e.g., assemblies) and associated processes on the jobsite.

KEYWORDS: *Augmented Reality, spatial temporal constraints,*

❖ INTRODUCTION

Nowadays, construction projects are becoming increasingly more complex due to the integration of the engineering systems required to meet the growing demand for a more sustainable, flexible built environment. For contractors and engineers, this trend requires systematic coordination and comprehensive understanding of the complex relationships of the interdependencies, interactions and constraints, among these engineering systems. The understanding of these relationships presents a significant challenge to mastering construction management practices in-situ. In addition, the globalization of the construction industry demands a highly qualified workforce that can to respond to the interdependencies and interact with the constraints inherited in complex engineering systems.

The lack of exposure to construction processes on the job-site results in students' lack of understanding of the dynamic, complex spatial constraints (e.g., how construction products are related to one another in a particular contextual space) and the temporal constraints (e.g., the dependencies for coordinating subcontractors' processes). In fact, the deficiencies in understanding construction products and processes is widely acknowledged by construction program graduates, including a lack of experience in applying construction-related concepts to real-world problems (McCabe, et al. 2008) and the exclusion of important contextual constraints typical found on jobsites (Sawhney, et al. 2000). Even though these constrains commonly exist in the management activities of the projects, there is a lack of appropriate pedagogical materials and media to enable instructors to effectively bring those job experiences (Jestrab, et al. 2009) into the classrooms that reflect what has been learned about the dynamics and complexities of such constraints.

Revealing the spatial temporal relationship of construction processes is a challenging task for educators, in particular, when using traditional instructional media in a classroom environment. The research question, therefore, is to determine how educators can bring the experiences of the dynamic, complex spatial and temporal constraints found on the jobsites into the classroom. In response to this question, this research uses pedagogical material in a way that leads to the students' understanding of the complex dynamic and spatial-temporal constraints by using Augmented Reality Technology (ART).

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INSTRUCTIONAL STRATEGIES AND MEDIA LIMITATIONS

Knowledge gaps and deficiencies in mastering spatial and temporal skills are consequences of the instructional strategies and media limitations. The limitations prevent the successful demonstration of critical construction products and processes in different context and at different levels of complexity. As these gaps are broadened in higher-level courses, they become a major bottleneck to more efficiently and effectively learning the reasoning skills needed to understand and master spatial-temporal complexities. Construction Management courses should equip students to connect concepts for better reasoning and problem-solving skills. For instance, training on reasoning on problems regarding management of space on the jobsite (a spatial-temporal constraint problem) should better enable students to respond to unexpected situations though improvisation. Thus, instructors should situate students in a learning environments suited to engage students in real-world, life situations including unexpected situations to improve their reasoning to accomplish construction activities within the project practices.

Typically, many existing CM curricula offer field trips or internships to remedy the instructional media limitations on instructing spatial-temporal and context conditions. This instructional strategy is an institutional sponsored experiential learning (Kolb and Kolb 2005). It involves a direct encounter with complex situations on the construction project under the assumption that the direct experience will lead to genuine meaningful learning. Students are exposed to the real-world environments within the projects of the construction firms they intern with. The challenge, however, is to expose the students to the context that adds value to the learning experiences and to involve the student in relevant experiences that significantly impact learning (McClam, et al. 2008). As instructors do not accompany students on the project job-site during the internships, they do not embrace coaching and debriefing, reflection, scaffolding and judging, among other teaching strategies. Students are left in a self-learning environment, which might not lead to the development of the required skills defined by the learning outcomes of CM courses.

The success of their internship experience requires a self-reflective active learning participation and intrinsic motivation (Levesque-Bristol, et al. 2010). These conditions demand an active participation to create a context of problems and site-settings at hand by observing and reacting on the jobsite. The demand for the active participation of learners problematically approaches the successful internship practice, as the conditions for participation are not suitable for many students. The intrinsic motivated students might navigate through situations on the jobsite within more reflective enriching activities by opening themselves to changes in their understanding of the observed project practices, other students participating in internships may not be able to sustain such practices with the same motivational level.

Furthermore, additional socio-cultural and economical related issues arise for the CM student population for their field trip participations. For instance, their successful internship engagement on jobsites when universities or institutions are located at considerable long distances from the practice site. Fitting academic work in tight schedules and restricted mobility to the jobsite (e.g., students may be residents at geographical distant locations and from areas with difficult access to the chosen jobsite) are some examples. These issues result in critical barriers that prevent certain students' from taking internships, which leads to disparity conditions among students. It is implied, therefore, that opportunities for learning on field trips are difficult to include within all the courses in the CM curriculum that benefit all CM student populations. Although it seems plausible that the resulting differences should be avoided or overcome, this research values such differences as they emerge as a resource for learning. Specifically, this research uses such differences to better design pedagogical material.

ART USE AS PEDAGOGICAL MATERIAL

This research uses Augmented Reality Technology (ART) as an instructional mechanism to virtually incorporate jobsite visits through the perception of augmented reality. ART enhances the physical, real-world environment through a computer-generated sensory input. For example, ART enables CM students to enhance their perception of the jobsite and, more importantly, have unlimited access to otherwise limited opportunities to participate in jobsite experiences.

ART is a technology-based tool that enables users to perceive artificial layers of computer-generated information (Azuma, et al. 2001, Haller, et al. 2007), including a combination of both the real environment and computer-generated information (Bimber, et al. 2005). This technology includes video, graphics, and geographical positional systems to mediate and enhance the human's perception of reality (Barfield and Caudell 2001). This research demonstrates that the ART supports CM students in having unlimited access to otherwise limited opportunities to participate in jobsite experiences.

While ART as an instructional mechanism is used to virtually incorporate jobsite visits, the design of instructional technology focuses on the creation of case studies. The case studies take place during any construction phase of a project and they are designed according to a required CM outcome based on a particular CM course of study. The purpose is to fully demonstrate the spatial temporal constraints in classroom environments to effectively bring the exposure of on-site experiences during any phase of the construction projects into construction courses. This set of case studies is a pedagogical resource that enables instructors to replicate such cases into other courses in the CM program, including their use by the entire CM academic community. The case study focuses on the essential elements of a real job-site problem. Thus, experts (instructors, professionals) have provided input in the assembly of the virtual objects and the simulations with ART for each one of the case studies developed.

Augmented Reality (AR) components assist students, for instance, to better understand concepts such as the management of space- a case study- (arrangements and potential conflicts in construction processes). Such concepts are easily incorporated and integrated into the case study. Augmentations vividly illustrate, for instance, the use of materials and construction safety- a case study topic.

For pedagogical purposes, therefore, ART enhances the learners' perception. ART serves as a supplementary tool to perceive and to identify spatial-temporal constraints through the interaction of virtual elements and the representations of real environments. The implementation of ART enhances the learners' awareness and understanding of the construction products, processes, sequences and problems found within the context of the project.

This researcher anticipate that the use of ART in the classroom will enable the enhancement of problem solving and learning visual, auditory, and kinesthetic skills for CM students. In summary, as the focus of this investigation is the understanding of methods and strategies to enhance students' learning within CM courses, this research effectively deploys ART to emulating real job-site experiences in order to enhance students' learning.

METHODOLOGY AND APPROACH

Simulations of continuing construction activities from job sites are performed through ART as a research strategy. The research subjects are students and instructors using this instructional methodology. The methodology is designed to enable real-world learning experiences with the use of ART. The objective of the implementation phase, for instance, is to build the prototype using an augmented reality teaching and learning environment.

The approach has three basic steps: (1) Rendering virtual objects and their composition- by focusing on the design and implementation of the prototype; (2) Simulations- aimed at developing situated superimposed real-world images using ART; and (3) evaluation and assessments, which consist of generating the required tests using case studies.

In creating a learning context and in order to capture and organize information from the construction site environment, and as part of the implementation process, the following is an illustration of the method used to create the computer-enhanced objects.

Virtual Models Generation.

The models consist of a set of computer-generated virtual objects designed to meet instructional objectives. The objects themselves have a set of variables that were manipulated by the user. The object designs are aimed at occupying a continuum within construction activity to meet the intended learning aims including the activity context (i.e., the object designs address the specific learning goals, such as the number of virtual objects that represent components and equipment for a particular activity). The set of virtual objects are built using 3D CAD platforms and the available library of geometric objects.

Virtual Object Composition

The set of stored video clips and images are composed (connected) to the virtual model objects. These virtual model objects are superimposed on the selected images from the video clips and set of stored video clips and images. The composed virtual objects allow users to contrast real-world images with the virtual objects, generating the AR experience. Figure 1 shows examples of video frames used by the researchers to compose the virtual objects. The generation of videos includes areal images taken from unmanned flying devices to provide visualizations of the jobsite context by involving broader views, since fix locations limit the ability to capture such views (see Figure 1). The researchers use an AR platform to coordinate the images and the virtual objects for each case study. The virtual objects' designs occupy a continuum within construction activity to meet the intended learning aims by including the activity context in the scenario (i.e., the objects' designs incorporate specific learning goals, such as the number of overlaid objects that represent temporary structures to build an assembly for a particular activity).

The focus is placed on what learners need to acquire on spatial and temporal constraints for CEM activities. The

learners-ART interaction is possible through the development through an AR video composition application. The video will capture the main components and CEM activities of interest and the context (physical and social) of the construction environment. The video output is a set of video images, which are edited, tagged and stored using computer applications such as SynthEyes (Anderson-Technologies 2014). As this research develops, the researches plant to develop an AR in-house computer application, using an AR development platform such as Vuforia® (Vuforia 2014) over Unity-3d extension (Unity-Technologies 2014) - a game engine and integrated development environment- for broad compatibility. Experts and graduate students manually localize and map the virtual objects into the image coordinates.
The sensory input data of the proposed model is mostly visual. Thus, the video captures the main components and CEM activities of interest and the context (physical and social) of the construction environment. The video output would be a set of video images, which will be edited, tagged and stored using computer applications such as SynthEyes (Anderson-Technologies 2014).
Several studies have shown that the synergy of multiple visual resources provides a powerful tool for students to understand many complex and abstract engineering concepts/solutions related to dynamic construction processes (Teasley, et al. 2000). In addition, understanding the means and methods of the way a product is put together under particular project conditions gives construction management students a broader perspective when they actually participate in product design (Marc, et al. 2007).

Simulations

In the classroom, students manipulate superimposed real-world images as they access and retrieve the images through a computer application in the classroom. At the same time, the instructor uses a multi-display panel to show the view of the same field images/streaming video with or without the virtual models (i.e., the instructor will illustrate and assist the learning process, by showing the composite or non-composite set of images, including the superimposition of the computer generated objects and other auxiliary information).
Thus, this research uses a video device to capture particular scenes on the jobsite. The video device is positioned in a strategic, safe place to allow capturing the main components of the construction project environment. The selection of the construction activities and the broadcast time is arranged with personnel on-site. The video is further filtered, edited, tagged and stored in a database. The data output consists of a set of video clips and images, classified according to the construction process and materials used to execute a particular construction activity.

Validation and assessment

(a) Exterior Wall Section

(b) Roof Section

Figure 1: Aerial images captured from an unmanned flying device.

This step assesses the learners' problem solving capabilities related to CM spatial-temporal constraints. It is aimed at validating the learners' ability to solve problems when using the ART intervention and when learners use traditional materials methods. The later is used as a control group. CM problem solving capabilities denotes here the learners' ability to obtain CM background knowledge with existing constraints by articulating the problem through a technical communication to formulate feasible solutions. It is expected that the learners use their own criteria to achieve a desired outcome. However at the learners' educational level, anticipation of alternative solutions and opportunities to reach the desired outcome are not taken into account.

It is critical to indicate that the learner's ability in tying together background knowledge and the existing constraints to reach an outcome implies recognition and articulation of factual CM information and constraints. For example, to solve a problem in estimating practice, the understanding of the construction processes, building systems, construction products, and productivity is required.

To contribute to the problem solving process, traditional tools and techniques are required (e.g., paper-based drawings and text based specifications). The assumption is that by using traditional tools, researchers will have a clear comparison to the ART intervention for problem solving, since it is possible to identify the modus operandi and the effectiveness in reaching the expected outcome. When using any tools, researchers are assessing the learners' ability to select tools and the most appropriate method for its use. Research will secure that the highest quality of the information and data is incorporated as a tool, since this information and data is used to build the problem.

The researchers' strategy to assess problem solving is on formulating an ill-defined CM situation (e.g., estimating and scheduling) where the learners' spatial-temporal abilities are essential. Poorly conceived CM definitions, for instance, consist of poorly defined, incomplete parameters where fundamental CM knowledge is required to anticipate an outcome. It is expected that learners will have an extended knowledge of the available tools, since tools are integrated into the problem solution. Understanding of the use of tools and their limitations are therefore assessed.

The student assessment strategy also incorporates questions in a semi-structured interview for a more consistent and accurate assessment. The questions will be built according to the following assessment aims (American Society of Civil Engineers. Body of Knowledge Committee. 2008, Anderson and Krathwohl 2001):

- CM Knowledge: The student's ability to remember the CM material. It implies recalling the appropriate specific facts and the learned CM concepts (e.g., fundamental concepts of construction techniques and methods) to contribute to a problem-solving outcome. CM knowledge involves having the lowest level of recollection of fundamentals to enable the definition of meanings (discover meanings), concept descriptions (identify means, properties, and qualities) by grouping, listing, and recognizing. Once the definition and the concept description are materialized, the learners should be able to reproduce, select, and state the defining problem features.
- CM concepts comprehension: As a step beyond the concept description and definition that define the problem features, CM comprehension aims at the learner's ability to grasp the meaning of the CM concepts. It involves the interpretation of the available tools and information and data within the problem. Interpretation denotes the ability to summarize, and explain the CM concepts involved in the problem, so that the learners are able to predict or establish an effect as the outcome of solving a problem. The learners' abilities to summarize and explain are characterized by their ability to translate and map from a system of symbols (geometries in the drawings) to another system such as a text-based system. This is a basic level of understanding of the CM problem, where the learner is able to explain and discuss details (e.g., give examples, perform generalizations from details) and describes and distinguishes differences (elements interactions, including properties and qualities).
- CM concepts application: This aim refers to the learner's ability to use the learned CM concepts, methods, and theoretical principles in concrete situations, including new or innovative ways. Learners' are able to solve (find answer, explanation), apply (find uses for particular purposes or cases), use tools (to a particular purpose), plan (articulate, contribute, implement, and provide a solution or outcome), conduct related activities (carry out reports), organize (order elements in the construction process), and explain (broad clarification to give reason for or cause).
- CM problem analysis: This aim denotes the CM student's ability to separate the components parts of an assembly by separating or breaking down elements for close examination. The analysis activity relating (mapping) parts to another part or a group of parts for a better understanding of the structure or organization as whole (e.g., mapping the assembly parts to understand the components functionality within the assembly-wall structure). The analysis leads to the organization of parts into a systematic planning and coordination of the systems involved and to looking at the parts' functionality as a whole. To reach the proper outcome, the learners compare the parts' quality and properties, by identifying particular features in order to contrast the differences. Thus, the learners are able to infer and communicate related meanings.
- Synthesis of CM concepts: This aim refers to the learners' ability to assemble a new whole set or group (by properly and orderly fitting parts) as an outcome through interpretations. It is bringing into existence a new plan (arrange parts, devise the realization of CM concepts), and design or creation according to a plan. It is putting together factors into consistent and complex settings, to reveal and develop hidden features, to assemble and fit (adapt by means of changes and modifications) disparate elements into specified and suitable conditions. It includes the organization of concepts, which has specific functions into coherent units, and conveys planning and

coordination of individual efforts.

• CM conceptualization evaluation: This aim refers to the learner's ability to judge the value of concepts, which are definitions of elements for a given purpose, by meeting defined criteria (e.g., subcontractors' required conditions for execution of a assembly task due to constrains- such as costs- and quality/property conditions). Learners judge and analyze the significance of CM elements and concepts by justifying their use and by determining their importance. It involves critical analyses and self-assessments.

CASE STUDY EXAMPLE

A typical upper-level class in CM curricula is the Construction Methods course. Its focus is on construction processes found in construction of building and infrastructure projects. It covers, for instance, the utilization of construction equipment within construction processes, during all phases of the project (i.e., planning, scheduling and control from the initial phase of construction to the end phase until the close-out). The course requires students to become proficient in decision-making, problem solving, and prediction and evaluation of construction products and equipment for the involved processes.

Students rely on concepts learned in previous lower-level courses. Therefore, strong connections to the lower-level courses' subjects and concepts are required to learn new knowledge and assure knowledge transfer. For example, knowledge of the behavior and properties of materials, assembly composition, and functionality of the building systems are essential to successfully understanding construction processes. Basic knowledge from low-level courses is also required to comprehend the spatial arrangement of materials and location of the equipment during a specific time interval.

Figures 2 and 3 illustrate the formwork assembly process of the cast-in-place reinforced concrete beams of an infrastructure project (interstate on-ramp). This construction process (the assembly process) has an intensive use of construction equipment: scaffolding equipment and formwork. Scaffolding is a temporary, assembled and erected, modular structure to support materials and workers on the construction site. It also provides safe access to the workers so that they can transport material and have mobility within a confined space. Formwork is the structure used to support wet concrete. Key elements of formwork equipment are the standards (vertical scaffolding that support the mass of the structure to the ground), ledgers (horizontal tubes that connect the standards), and transoms (tubes positioned at certain angles that reinforce the ledgers).

Positioning the formwork require instructions to secure a safe structure and a rapid erection process on site. The formworks' structural stability, for instance, is at risk when there are failures in the assembly processes, soil conditions, and in the structural strength of the materials.

Learning the assembly process for each component of this temporary structure and relating the process to the typical conditions of a project is critical. For instance, conditions of space are unique to a particular project. Also conditions of the ground (soil) are very complex to generalize. The instruction of tolerance, such as the horizontal movements in the joints under loading conditions, is fundamental since soil movements may cause changes in the loading conditions that substantially affect the stability of the scaffolding system.

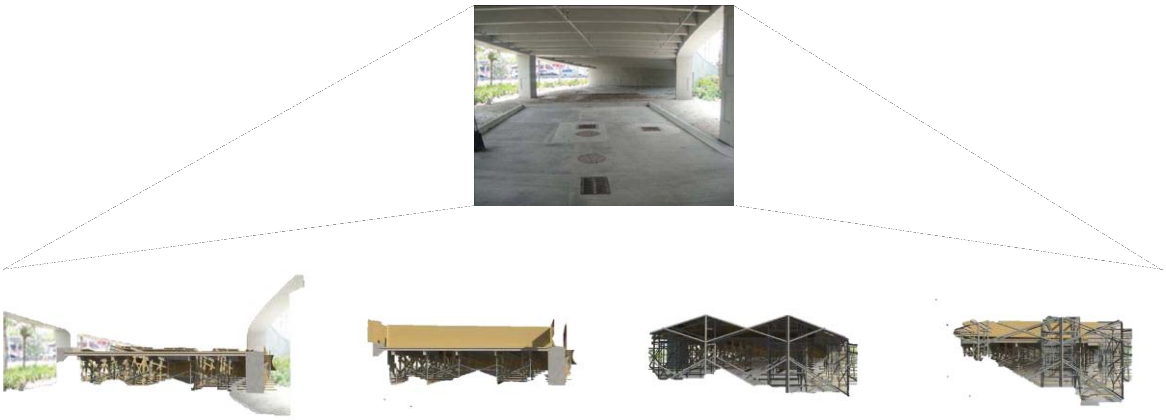

Figure 2: Virtual objects to visualize formwork assembly method

As shown in Figure 3, ART enables students to learn within the context of the project position and assembly by directly manipulating the assembly parts represented as computer generated virtual objects. At full scale, students are able to visualize the critical elements, for instance, for load transfer. It is important to note that the detailed assembly process of this scaffolding equipment is not included in a typical construction methods course.

Figure 3: Sequence of images to visualize working and access spaces during the formwork assembly

CONCLUSIONS

This research provides a viable solution to bringing field experiences to classrooms, including an open source, cost-effective mechanism for sharing educational resources among participating faculty members. Such a capability would be beneficial to a wide range of CM and engineering education programs, since the shared challenges and the proposed approaches are common to many other engineering disciplines. It is anticipated that the ART users will significantly grow as well as the users' feedback based on trustful relationships among users (Issa and Haddad 2008).

Results of the project directly impact the teaching and learning of a wide variety of construction engineering courses, which rely heavily on students' spatial-temporal cognition skills of building systems and construction processes

In particular, the resulting proof of concept and the data of this research might be used to inform the design of a scalable teaching/learning environment (i.e., the follow-on ART design environments within the classroom will facilitate ART use and its implementation within CM programs from other US institutions).

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PART III: BIM & GIS: INTEROPERABILITY & STANDARDS

BIM-ENABLED APPROACHES TO CODE-CHECKING: CHALLENGES WITHIN THE AUSTRALIAN REGULATORY CONTEXT[1]

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ABSTRACT: *At present building designs are manually assessed for compliance with the Building Code of Australia (BCA). Traditionally, this certification process is performed using two-dimensional (2D) drawings that can result in fragmented information being shared between stakeholders. Moreover, some clauses of the BCA contain open-ended conditions that certifying authorities can only rely on their experience to determine. These issues may result in inconsistent assessment of building design. Building Information Modelling (BIM) and its applications are seen as vehicles enabling rigorous analyses to be conducted during the design process. Several code-checking systems have been developed but few have been successfully implemented and adopted. In this research a BIM-enabled code-checking system (BIM-CCS) has been developed to assist stakeholders by streamlining the design and certification processes. Autodesk® Revit®2014 is used as the software platform for the BIM-CCS. This BIM-CCS prototype has been designed to assess BIM models against commercial buildings (Class 5 to Class 9 buildings) and Section C Fire Resistance codes of the BCA. Several challenges, including (1) class of building, (2) rise in storeys and (3) fire-source feature, are discussed in this paper. These challenges stem either from the lack of information provided in BIM models or the need for further calculations. Proposed solutions to these challenges are then addressed. Some challenges can be overcome by additional activities while others are more problematic and need related parties to work out collaboratively. Although some challenges need regulatory content and BIM information to be aligned, this study shows the potential and opportunities for the development of BIM-CCSs for Australia. Preliminary evaluation results demonstrated that the development of a fully functional BIM-CCS will require building-related professionals to participate in refining the BCA to harness the potential of this new technology.*

KEYWORDS: *BIM, BCA, code-checking, BIM-CCS, Fire Resistance.*

❖ INTRODUCTION

In Australia, building designs must comply with building regulations to obtain construction certificates, otherwise construction works are not permitted to commence. The process of assessing whether designs comply is performed manually by certifying authorities and may be error-prone and time-consuming (Choi and Kim, 2008; Tan et al., 2010). Typically, two-dimensional (2D) drawings are used to represent information and assessed against the Building Code of Australia (BCA) (Australian Building Codes Board, 2013). The widespread use of 2D drawings has influenced the manner in which building codes have been legislated. 2D drawings, however, are generally poorly coordinated and lead to fragmented information between stakeholders (John et al., 1997). Furthermore, several BCA clauses contain open-ended conditions and/or exceptions. Individual certifiers may rely on their own experiences to determine whether drawings comply or not (Nawari, 2012a). These anomalies lead to inconsistent assessment results. Where building designs do not comply, schedule delays and cost overruns may ensue.

Building Information Modelling (BIM) enables building projects to be designed and coordinated in a rapid, visualized and collaborative manner (Pollock, 2010). The uses of BIM have been shown to improve information sharing, strengthen communication, enhance collaboration, increase productivity and reinforce quality control (Azhar, 2011). These benefits are increasingly encouraging the construction industry to incorporate BIM and its extensions into the design process. Relevant research has identified that BIM and its extensions enable complex analyses to be conducted, thereby streamlining the design process (Rogers, 2012). This highlights the potential of the BIM-enabled code-checking systems (BIM-CCSs) to be used as vehicles for compliance (Nawari, 2012b). In addition to enhancing the efficiency and consistency for certifying activities, BIM-CCSs make it possible to highlight instances of non-compliance in visualized environments during the design phase (Eastman et al., 2009).

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However, certifying authorities in Australia do not use BIM-CCSs, and the certification process remains far behind other professionals in applying BIM-related technology (Kreider et al., 2010; McGraw Hill Construction, 2007).

Code-checking systems have been proposed since the 1960s (Fenves et al., 1995). The Construction and Real Estate NETwork (CORENET) project, initiated by Singaporean governing bodies, established a prototype in the domain of automated code-checking (Khemlani, 2011). It enables developers to obtain approvals using BIM models and thus demonstrates that code-checking systems may alter manual certifying activities. CORENET is seen as a basis for the evolution of code-checking systems such as Statsbygg (Norway), International Code Council (ICC, USA) and DesignCheck (Australia) (Eastman et al., 2009). Both of Statsbygg and ICC adopt the Solibri model checker as the platform for the compliance-checking activities. Solibri can communicate directly with IFC-based models, but only retrieves the object information it needs for pre-defined rules (i.e. accessibility rules). In addition to the inabilities to modify attributes for IFC models, Solibri currently cannot deal with code-checking of attributes not supported by BIM vendors (Greenwood et al., 2010). Of particular relevance to this study is DesignCheck, an application developed in Australia in 2005 (Ding et al., 2006). It adopts Express Data Manager (EDM) to communicate with IFC-based formats for compliance works and caters specifically for the requirements of disabled people (Australian Standard 1428.1) in the state of New South Wales (NSW). However DesignCheck cannot view 3D models and the reports it produces are in textual format only. These issues inherent in Solibri and EDM may impede these code-checking systems widespread adoption within the construction industry. More discussions about code checking systems can be found in the authors' previous paper (Shih and Sher, 2012).

Existing systems operate code-checking in accordance with specific building regulations (e.g. accessibility). Despite evidence showing that most BIM-CCSs (except CORENET) have not been implemented in the construction industry, they all provide potential and guidance for this study in the development of an Australian BIM-CCS. This paper reports on the development of a BIM-CCS focusing on commercial buildings and Section C Fire Resistance Code of the BCA (Australian Building Codes Board, 2013). A Design Science methodology has been used to set a framework for the BIM-CCS design (Hevner and Chatterjee, 2010; von Alan et al., 2004). The Design Science research involves development, evaluation and close collaboration with users in iterative manner. In this research a BIM-CCS is developed as an artefact outcome of Design Science research process. This comprises clarifying the requirements of the BCA, suggesting solutions for the identified requirements, designing a BIM-CCS program, examining the efficacy of this BIM-CCS and finally generating theories and conclusions. These five requirements form a large and complex framework, and discussing them in their entirety is outside the scope of this paper. This paper focuses on suggesting ways to address the identified requirements of building codes. In the next section, code-checking related activities are firstly addressed to inform the structure of the BIM-CCSs. Several key issues of the fire resistance codes as well as suggested solutions are then discussed in the following section. Finally, preliminary results for this study are briefed, and the ways to consolidate the BIM-CCSs for future development are discussed in the last section.

STRUCTURE OF THE BIM-CCS

Regardless of whether the BIM-CCSs noted above operate independently or via third-party platforms (i.e. Solibri) they generally include four activities (Shih and Sher, 2012):

filtering required information from BIM models,

interpreting building regulations into program rules,

examining the filtered information (the first activity) against the rules (the second activity), and

producing a report showing the results of examinations (the third activity).

Most BIM-CCSs support BIM models using IFC or IFC-based (e.g. ifcXML) formats (Nepal et al., 2013, 2008). IFC-based formats are promoted as vehicles for communicating between different BIM software (buildingSMART, 2009). This creates opportunities to engage many BIM vendors with BIM extensions, such as code-checking applications. In many cases, however, IFC-based models are not able to share all information between BIM vendors (Pazlar T, 2008). This undoubtedly impedes the potential of independent BIM-based extensions.

This study has used *Autodesk® Revit®* 2014 as a base platform for our BIM-CCS. Revit is recognized as having a larger BIM user-base than other BIM software (i.e. ArchiCAD) in many countries (Borchers, 2009). Furthermore, Revit contains an open-source code feature, Revit Lookup, which allows program designers to develop plugins and embed them into the Revit platform. The structure of our BIM-CCS platform is depicted in Figure 1 below. Within this structure, the fire resistance codes are firstly interpreted to obtain the requirements through semantic analysis methods. The interpretation process is further discussed in paper (Shih et al., 2013). The BIM model information is then explored through the Revit Lookup according to the requirements of clauses. The rules afterwards are created based on the analyzed results of interpretation processes and written as a plugin embedded in Revit. After a code-checking activity has been completed, users can obtain a visualized and interactive report of results. Reports can also be produced in *pdf* document format. Plugins can augment Revit's abilities to assist designers to improve efficiency, enhance qualities and solve problems for design projects during the design process. Moreover, users are allowed to modify models directly in the Revit environment when BIM-CCS identifies instances of the non-compliance, while users cannot revise models through external platforms such as Solibri. Importantly, plugins can help Revit enhance the IFC project data to communicate with other BIM software (i.e. ArchiCAD) and get improved interoperability (GRAPHISOFT, 2014). This makes it possible for BIM models from other vendors to engage in code-checking activities through the Revit platform.

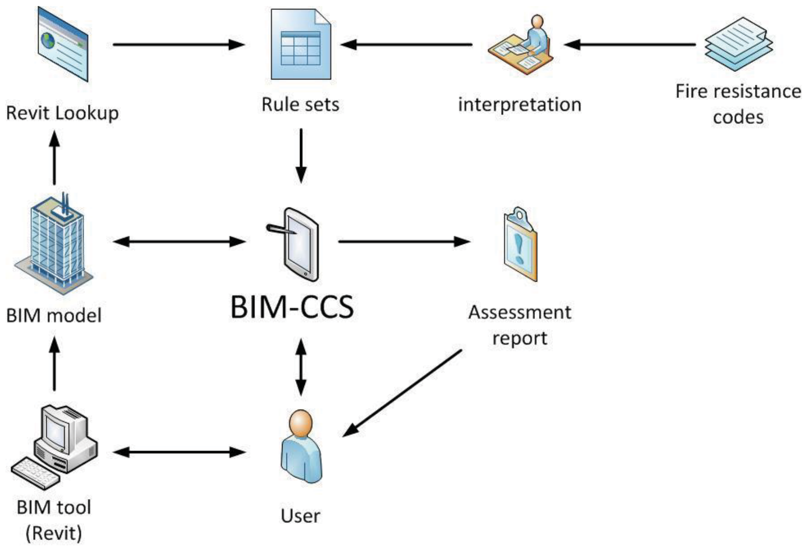


Figure 1. The structure of the BIM-CCS

CHALLENGES AND PROPOSED SOLUTIONS

The BCA regulations are intended to ensure that building designs achieve minimum requirements of health, safety, amenity, and sustainability. However, some clauses of the BCA are difficult to interpret especially where they contain cross-references to other sections. Moreover, some clauses set requirements not supported by BIM attributes, such as *fire-source feature*. Consequently, developing a system that interprets and applies these regulations is challenging. Several issues within Section C of the BCA are discussed below. The first priority in Section C is to establish the *type of construction*, which significantly impacts on the assessment of the other codes. It is determined by two conditions: *class of building* and *rise in storeys*. These are defined in turn as:

'The classification of a building or part of a building is determined by the purpose for which it is designed, constructed or adapted to be used'(2013, p. 41)

'Rise in storeys means the greatest number of storeys calculated in accordance with C1.2.'(2013, p. 33)

The ways to identify these two conditions are discussed in the following sections. In addition, specification C1.1 in Section C sets standards for the *fire-resistance level* of building objects (e.g. walls and columns). A significant issue is the distance between *exterior walls* of a building and *fire-source feature* of adjacent properties. These issues are discussed further in the following sections.

Class of building

The BCA classifies a building into two types: residential and commercial. Only commercial buildings (shown in Table 1) are examined in this study. Some categories of commercial buildings may contain sub-categories (for example Class 7 buildings include Class 7a car parks and Class 7b warehouses). In current certification processes, developers need to lodge applications including design plans (i.e. site plans and floor plans) with local councils, thereby enabling accredited certifying authorities to determine the correct *class of building*.

Challenges

In a design project, designers may not be able to identify the *class of building* correctly until consultants are involved in the design processes. This may result from that designers are unfamiliar with the complexities of *class of building* for a storey and/or a building. In some cases, consultants and even certifiers may determine the *class of building* inconsistently. For example, various building practitioners may regard an assembly of people in a building for a particular activity as Class 6 or Class 9b. In BCA 2008 (Australian Building Codes Board, 2008), the classification of a Class 6 use relates to any 'bar' area (which could include an assembly of people to meet, socialize and also possibly be entertained), whilst the Class 9b classification also refers to an assembly building where people may assemble to be entertained. Although the Class 6 building in BCA 2009 (Australian Building Codes Board, 2009) refers a 'bar area that is not an assembly building', this inconsistency can result in different assessment conclusions. In such cases, the *fire-resistance level* of building elements, for instance, can be downgraded. This is a challenge for BIM-CCSs as ambiguities like these cannot be catered for.

Table 1 Classification Summary of Commercial Buildings and Structures defined in the Building Code of Australia (Australian Building Codes Board, 2013)

Class	Definitions	
Class 5	An office building used for professional or commercial purposes, excluding buildings of Class 6, 7, 8 or 9.	
Class 6	A shop or other building for the sale of goods by retail or the supply of services direct to the public.	
	Example: café, restaurant, kiosk, hairdressers, showroom or service station.	
Class 7	A building which is -	
	Class 7a	a car park.
	Class 7b	for storage or display of goods or produce for sale by wholesale.
Class 8	A laboratory, or a building in which a handicraft or process for the production, assembling, altering, repairing, packing, finishing, or cleaning of goods or produce is carried on for trade, sale or gain.	
Class 9	A building of a public nature -	
	Class 9a	a health care building, including those parts of the building set aside as a laboratory.
	Class 9b	an assembly building, including a trade workshop, laboratory or the like, in a primary or secondary school, but excluding any other parts of the building that are of another class.
	Class 9c	an aged care building.

Suggested Solutions

Ideally, a building design needs area plans as well as parameters of *class of building* for each area within a floor. This enables design proposals to be coordinated by project teams and certifiers from design through to certification. In reality, however, area plans are not always produced and the embedded parameters in some BIM applications may not allow users to choose *class of building*. Although users can manually add parameters for *class of building* in a parameter set, this requires additional effort on the part of stakeholders during the design process. As designers making room tags in their designs are a norm, a suggested solution adopted in this study, preventing stakeholders from extra works, is to use room tags for determining *class of building* (Figure 2). All information related to the room can be found in the Revit Lookup interface (Figure 3), for example the storey it is located on and its floor areas. This system has included a dataset element in a table form that contains the name of each room specific to each *class of building* (Figure 4). We have collected and categorized several room names in each *class of building*. For example, *cafeteria* and *instruction* belong to class 6 and class 9b respectively. This table also allows users to add or modify names for the *class of building*. This provides users with flexibility when a case (such as the bar area) needs modification.

It can be argued that this approach is inconsistent because the ways in which stakeholders nominate room names can be varied. However, project stakeholders generally nominate room names in a consistent manner. Therefore, once this table has been set up initially, there is no need to make modifications unless the clauses change. Another benefit is that no extra workload is required for stakeholders during the design process.

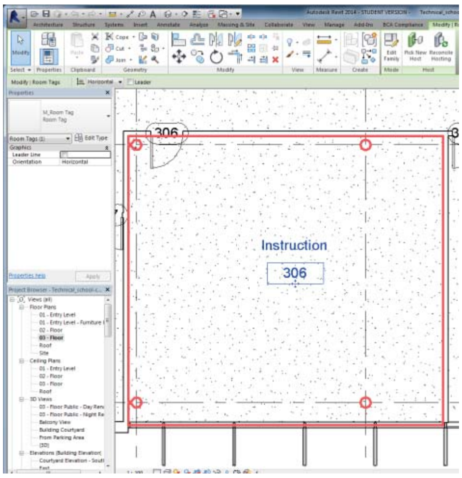


Figure 2. An example for room tag use.

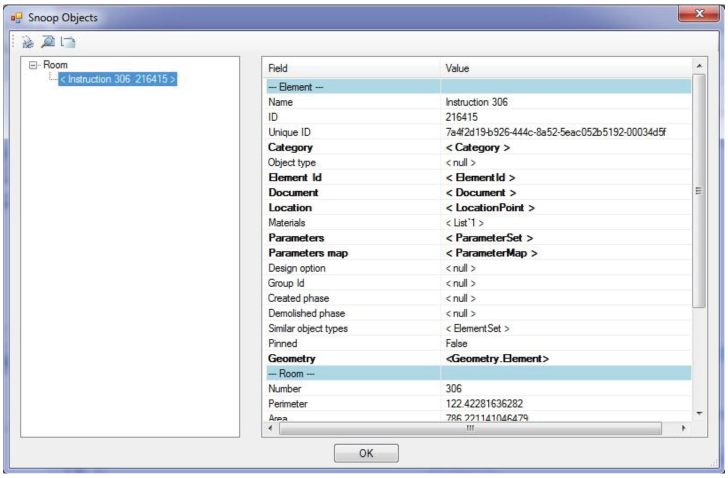
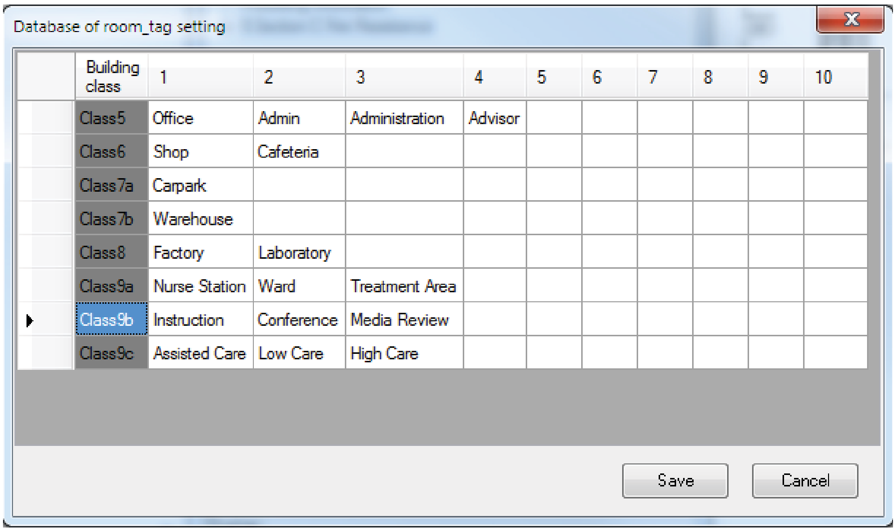


Figure 3. Room tag information shown in Revit Lookup.



Database of room_tag setting

Building class	1	2	3	4	5	6	7	8	9	10
Class5	Office	Admin	Administration	Advisor						
Class6	Shop	Cafeteria								
Class7a	Carpark									
Class7b	Warehouse									
Class8	Factory	Laboratory								
Class9a	Nurse Station	Ward	Treatment Area							
Class9b	Instruction	Conference	Media Review							
Class9c	Assisted Care	Low Care	High Care							

Save Cancel

Figure 4. Table for the *class of building* setup.

(All Autodesk screen shots reprinted with the permission of Autodesk, Inc.)

Rise in storeys

The importance of *rise in storeys*, in general, is the more storeys a building has, the higher *fire-resistance level* is required. A building having four or more storeys requires the highest level of fire-resistant *type of construction*. A general definition of the *rise in storeys* is that it is the sum of the greatest number of storeys above the ground, and within the *external wall* and roof space. This highlights several key requirements when creating BIM models.

For example, within the modeling process, site surfaces can define a finished or natural ground. In addition establishing storey planes for different levels shows the height of storeys, and setting a wall function as exterior for *external wall* helps determine the boundaries of a building.
Not surprisingly, the ways to gauge the *rise in storeys* include several exceptions. The top level is not counted as a storey when it only contains service units (e.g. a heating or water tank). Furthermore, a storey classified in class 7 or class 8 may be counted as two storeys where such a storey has an average internal height of more than six meters within a two storey (or more) building. In addition, a *mezzanine* (or *mezzanines* at the same level) may be counted as an independent storey once its aggregate floor area exceeds 200 m^2, or if not, its aggregate floor area is more than one third of the floor area of the room. Some information unfortunately cannot be provided directly from BIM models and further calculations are necessary. In this regard, several challenges and suggestions are described below.

Challenges

Service units are one of several challenges that confront those designing BIM-CCSs. The BCA (Australian Building Codes Board, 2013) says '…at the top of the building contains only heating, ventilating or lift equipment, water tanks, or similar service units or equipment' (p. 102). The term 'similar' is an ambiguous term that systems cannot accommodate. The average internal height within a storey is another challenge. The information from BIM models can only establish the distance from one storey plane to another. This does not represent the accurate average internal height once floors, ceilings or roofs are divided in areas by diverse heights within a storey. A further calculation is needed to obtain the average internal height. A further challenge, within BIM software, is that there are no embedded parameters to distinguish storeys or *mezzanines*. In most cases, designers may set an individual storey plane for a *mezzanine* (or *mezzanines* at the same level), while some designers may create *mezzanines* based on the storey plane of its next storey. All these challenges prevent BIM-CCS from obtaining correct model information for examination.

Suggested Solutions

In order to find whether the top storey contains only similar service units, two issues need to be clarified. The first is to explore the mechanical equipment objects (in the service units) and the second is to check the function of the space on the top storey. Once this space is used for a purpose that is in addition to placing service units, this storey needs to be counted. This means that the room space and the mechanical equipment objects on the top storey need to have separate parameters to identify their use. This enables the use of the space on the top storey to be determined correctly. However, these two parameters unfortunately are not supported by BIM applications. This study uses the ways that explore whether the space on the top storey contains a room tag. Once a room tag is found, regardless of mechanical equipment, the top storey must be counted as one storey and vice versa.
Calculating the average internal height is problematic when, as mentioned in section 3.2.1, the floors, ceilings and roofs have divided areas with varied heights and these divisions are not aligned and overlap. The solution this study has adopted is to divide the overlapped areas between floors and ceilings (or roofs) into segments to ensure each segmented area does not have more than two heights. The volume of each segment is then calculated. All segments' volumes are summed up and divided by the floor area to obtain the approximate average internal height.
As noted in the previous section, designers can only create floors on storey planes whether the floors are used as storeys or *mezzanines*. BIM software treats a storey and a *mezzanine* (or *mezzanines* at the same level) in the same manner, and thereby no parameters can tell them apart. As *mezzanines* are treated as storeys, additional constraints are needed to exclude the *mezzanines* that should not be counted as storeys. Calculating the floor areas of each storey is used to determine whether storeys are to be considered as *mezzanines*. The BCA clause sets constraints for *mezzanines* as '…a *mezzanine* is regarded as a storey in that part of the building in which it is situated if its floor area is more than 200 m^2 or more than 1/3 of the floor area of the room…'(p. 102). This means that *mezzanine* levels are seen as storeys. The floor area of every storey is then checked to see whether it exceeds 200 m^2, or more than one third of the floor area of its next storey.

Fire-source feature

Specification C1.1 of the BCA sets the required *fire-resistance level* of building elements (e.g. walls and columns) according to *type of construction* and *class of building*. An additional requirement for determining *fire-resistance level* of *external wall* requires measurement of the shortest distances from *external wall* to *fire-resource feature*. The *fire-source feature*, according to the definitions of the BCA (Australian Building Codes Board, 2013), is defined as '(a) the far boundary of a road, river, lake or the like adjoining the allotment; or (b) a side or rear boundary of the allotment; or (c) an *external wall* of another building on the allotment which is not a Class 10 building' (p. 27). The challenges that arise from these conditions are described below, followed by suggested solutions to address them.

Challenges

According to the aforementioned clauses, *fire-source feature* is a necessity in BIM models. They determine the minimum *fire-resistance level* for *external wall* according to the distance between them. However, the nature and location of *fire-source feature* presents challenges to the design process. Were *fire-source feature* to be included in drawings, designers would need to create many incidental objects (such as roads, rivers or buildings next to the building being designed). In most cases, designers spend little time creating such surrounding objects. Moreover, roads, rivers and similar objects can only be created as surface objects, which have no specific parameters to distinguish them. These all complicate the measurement of the distance between *external wall* and *fire-source feature*.

Suggested Solutions

Due to a fact that current BIM software cannot provide these *fire-source feature* objects with specific parameters, we were only able to measure the distance between *external wall* and boundaries of allotments. However, the information relating to the boundaries of allotments provided by Revit is incomplete because Revit can only identify the vertices of the allotment surface. Therefore, additional calculations are required to establish the boundaries. All vertices need to be connected to calculate the boundaries but there must be connections within the allotment that are not boundaries (see the dash lines in figure 5). The angles for each two connected lines are then estimated. The two intersected lines that make the largest angle are determined as the boundaries, for example the ∠BAE intersected by $\overline{AB}$ and $\overline{AE}$ is the largest (which is larger than ∠BAC, ∠CAD, ∠DAE, ∠BAD and ∠CAE), thereby $\overline{AB}$ and $\overline{AE}$ are determined as boundaries. Both of *external wall* and the boundaries of the allotment respectively are then divided equally in one thousand segments to estimate the minimum distance between them.

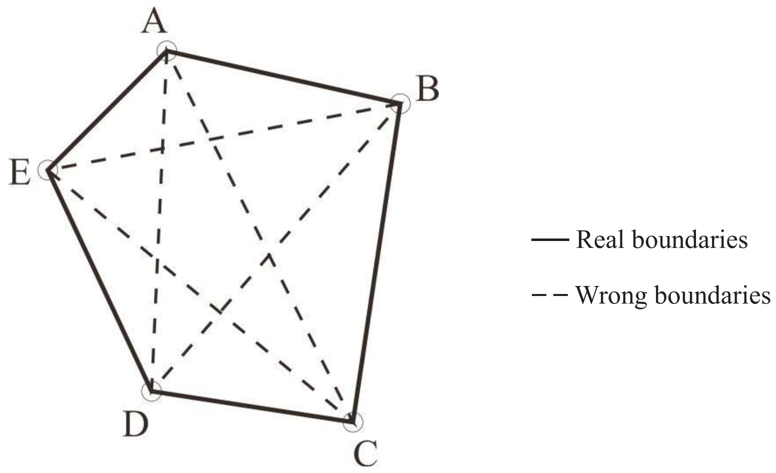


Figure 5. Determine the boundaries of allotments

It can be argued that this approach may produce inconsistent results if the allotment is not a convex polygon. A concave polygon may not be estimated correctly (such as the area CDE shown in the Figure 6). This may result in the incorrect distance between *external wall* and boundaries of the allotment. However, an additional constraint attached to this approach can prevent this. The incorrect estimation of the boundaries may eliminate one vertex (i.e. vertex D in Figure 6). A constraint enforcing all vertices to be used can prevent the incorrect estimation and determine the approximately correct boundaries. The only condition that this study cannot address is a curved line that connects two vertices (which is a rare occurrence).

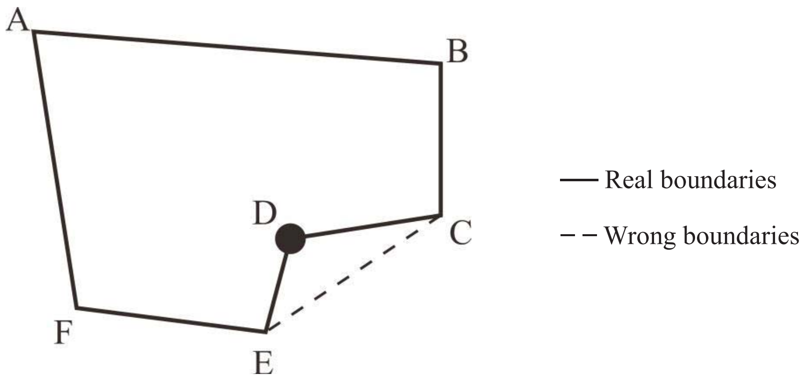


Figure 6. Exclude the exceptions for a concave polygon

DICUSSIONS AND CONCLUSIONS

Incorporating BIM into various applications such as construction schedule management and cost estimation has demonstrated that performance, productivity and quality of building designs can be improved (McGraw Hill Construction, 2007). This underpins the adoption of BIM-CCSs into design and certification processes by stakeholders, including team members and certifying authorities. This study has developed a BIM-CCS for NSW, Australia, specific to commercial buildings and Section C Fire Resistance of the BCA. Challenges and suggested solutions for the development of the BIM-CCS have been identified within three topics:

Class of building: Identifying *class of building* for a building design is problematic as consultants and certifiers can have different interpretations of the BCA. This study uses a table categorizing room names for each *class of building*. Users are able to modify names for each *class of building*. Once these are established initially, all stakeholders can assess their building designs without additional effort.

Rise in storeys: Calculating the number of the storeys has three exceptions. The first is excluding the top storey that contains only service units or similar. BIM applications have no parameters that identify service units. Therefore the function (*class of building*) of the top storey is used instead to determine whether the top storey needs to be excluded. The second is the average internal height within a storey that needs to consider floors and ceilings (or roofs) being arranged in different heights. We needed to divide spaces into segments and ensure that each segment has no more than two different heights. The total volume of segments is then divided by the floor area to obtain the approximate average internal height. Then the floor areas of *mezzanines* need to be checked, as *mezzanine* levels are treated as storeys. If they exceed 200 m^2 or are over one third of the floor area of its next level, these *mezzanine* levels are counted as storeys and vice versa.

Fire-source feature: This requires designers to create several surrounding objects (e.g. roads and lakes) to the building being designed. However, these objects have no identifiable parameters and only the boundaries of allotments can be used for measurements to *external wall*s. Establishing approximate boundaries requires calculations of angles constituted by every two connected lines. The largest angle of each vertex can determine the boundaries of allotments.

This paper has identified some of the challenges inherent in Section C of the BCA. Notwithstanding these challenges, this study has demonstrated the possibilities of a BIM-CCS to address the demanding and ambiguous fire resistance codes mandated in the BCA. Six accredited certifiers have examined the efficacy of the BIM-CCS for preliminary evaluations. Proposed suggestions for those challenges have been validated. Furthermore, they are in favour of the use of BIM-CCSs that enables construction project teams to secure building designs complying with the BCA during the design process. This highlights the potential for BIM-CCS to eventually assess BIM models for compliance in accordance with the requirements of the entire BCA. Moreover, our findings may also be beneficial for other BIM-CCSs designed for different countries and/or building regulations when they encounter similar challenges.

This study only deals with fire resistance and identifies gaps between BIM and building codes that need further investigations. Although our BIM-CCS has not yet been adopted by industry, we have addressed all the requirements of the BCA undoubtedly necessitates the engagement of professionals from many disciplines. In addition to knowledge of the BCA, expertise in BIM applications and programming skills in information technology is required, as are other related experts, suppliers and manufacturers. For instance, confirming the nature of service units may require BIM vendors and equipment manufacturers to collaborate. A library comprising all service units with required parameters can be established to assist project stakeholders. The involvement of all related professionals is necessary if the BCA is to be refined to fully benefit from the IT-related opportunities that BIM and code-checking applications such as our BIM-CCS offer. Changing technology, construction techniques and community expectations are encouraging the Australian Building Codes Board (ABCB) to agree to reducing redundant or unnecessary regulatory content in the next installment of building regulatory reform plan (Australian Building Codes Board, 2014). As discussed above, roads, rivers or the like need to be created in BIM models as *fire-source feature*. A solution might be that stakeholders reach an agreement by simplifying regulatory content, strengthening BIM tools and improving collaborative processes. This paper has outlined potential visions and demands of BIM-CCSs that may encourage legislative bodies, BIM vendors, project developers and building related professionals to spend time and effort to ease the ways in which BIM-CCSs can be incorporated into the design and certification processes.

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OPTIMIZED INTEGRATION OF UVAs SURVEYS, AND IMAGE-BASED MODELING STRATEGIES FOR DIGITAL TERRAIN MODEL RECONSTRUCTION[1]

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ABSTRACT: *This paper presents a strategy for digital terrain model (DTM) reconstruction using unmanned aerial vehicles (UAV), surveys, and image-based modeling technologies. The construction of a terrain model is considered critical since it can be used to study terrain transitions and conduct flooding simulations and field surveys. Existing methods use position data collected by Light Detection and Ranging (LIDAR) techniques to build DTMs. However, collecting position data using LIDAR is an expensive and time-consuming approach since a surveyor is required to enter the target area with numerous costly instruments regardless of the level of precipitousness. Therefore, this study proposes a strategy to utilize UAV vision and total station survey data to generate image-based models since a UAV has advantages on flexibility and cost compared to LIDAR. We have carried out a field test on a debris fan, which is located at the intersection of Laonong River and Pu-tun-pu-nas tributary. Firstly, we divided the debris into several parts and set 6 - 8 marks as ground control points (GCPs). Secondly, we used a UAV equipped with a digital camera to photograph each chunk from a height of 300 m. Finally, we performed post-processing of the image-based model using PhotoScan, a software application that can analyze aligned photos and build a DTM. The software aligns aerial photos, produces point clouds, and exports a DTM. We compared the results produced with the one gained from LIDAR; our strategy is relatively low-cost and time-efficient method to build the DTM. Precision was also improved from 1 m to 0.1 m. The results of this study suggest our method is more efficient and applicable for DTM reconstruction.*

KEYWORDS: *digital terrain model; image-based modeling; survey; unmanned aerial vehicle.*

❖ DIGITAL TERRAIN MODEL RECONSTRUCTION METHODS

Digital terrain model (DTM) reconstruction is considered critical in surveying. Initially, surveyors are required to bring heavy instruments, such as total stations, Global Positioning System (GPS) receivers, and surveying rods. This is both time-consuming and labor-intensive. Therefore, numerous new approaches are being developed to eliminate such disadvantages. For instance, Fritsch and Stallmann (2000) applied optical satellite imagery on orthography. Elaksher et al. (2002) used Light Detection and Ranging (LIDAR) data to reconstruct a 3D model. Niethammer et al. (2011) used a UAV to obtain the terrain imagery for a landslide investigation.

Optical Satellite Imagery

Fritsch and Stallmann (2000) mentioned that the application of high resolutions optical satellite imagery to build a DTM was an issue in their work. They used the orthographies from an optical satellite to construct a DTM of the southern part of Germany. The results showed that it is possible to use optical satellite imagery to build a DTM and the accuracy was close to 10 m.

Light Detection and Ranging Technology

Light Detection and Ranging (LIDAR) is a remote sensing technology that uses a laser to illuminate the target area and analyze the reflected light to measure the distance to the target. LIDAR allows one to obtain the point cloud of a target terrain. The accuracy can be very high; however, there is a requirement to divide the target area into numerous tiny chunks. Further, surveyors must carry the machine to every chunk.

Unmanned Aerial Vehicle Imagery

In recent years, the application of unmanned aerial vehicles (UAVs) with digital cameras for DTM reconstruction

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has become common. A UAV system can be classified into a fixed-wing UAV and a multi-rotor UAV. Vallet et al. (2011) used a fixed-wing UAV system to reach accuracy in the range of 15 cm at a flying height of 150 m. However, a wing-fixed UAV requires a broad and flat area for aircrafts to take off and land. Further, it is challenging to find such places in forests or besides streams. For these reasons, some researchers (Neitzel et al., 2011) began to use multi-rotor UAVs since they can take off vertically without requiring a long track.

STATE OF THE ART UNMANNED AERIAL VEHICLES

An unmanned aerial vehicle (UAV) is an autonomous aircraft that does not require a human pilot on board. Instead, it is controlled autonomously using microprocessors, actuators, and sensors that are located onboard. Furthermore, operators can control it remotely using radio communication with a ground station. A typical UAV system mainly consists of two major parts: the aircraft and sensors.

Aircraft

Nowadays, there are two primary types of UAVs, namely fixed-wing UAVs and multi-rotor UAVs as shown in Fig. 1. The fixed-wing UAV was initially developed for military applications. This technology has since become more affordable and has been developed to conduct aerial photography. However, a fixed-wing UAV requires a runway to take off and the takeoff weight is very limited. In comparison, the multi-rotor UAV was developed in the last few years. As opposed to a fixed-wing UAV, it does not require a runway to take off and can transport much heavier equipment. A multi-rotor UAV can be classified by the number of rotors it contains. Common multi-rotor UAVs are quadcopters, hexacopters, and octocopters. The number of rotors determines the total takeoff weight and hovering time of a multi-rotor craft.

Sensors

To control the aircraft autonomously, we need to equip sensors on the aircraft. For instance, it must have microprocessors to process the flight algorithm. A GPS sensor returns the coordinates, which can be used to localize the craft. Additionally, gyroscopes, a radio receiver, and a barometer also serve as important sensors in a UAV system. The aircraft can keep its position steady during flight using the gyroscopes. A radio receiver can receive signals from a manipulator so that the UAV can be controlled immediately. Finally, the barometer allows a controller to estimate the height of a UAV.

Fig. 1. Two types of UAVs: a fixed-wing UAV (left) and a multi-rotor UAV (right).
(http://low-powerdesign.com/donovansbrain/2013/06/29/build-your-own-personal-drone)

CASE STUDY OF THE PUN-TUN-PU-NAS TRIBUTARY

In order to verify the extent to which a UAV would assist in DTM reconstruction, this study conducted a field test as a case study. A manual survey was also completed for cross-validation.

Study Area

Our study area is a debris fan located at the intersection of Pun-tun-pu-nas tributary and Laonong River in Kaohsiung, south of Taiwan (see Fig. 2). Since it is a gentle section in a rapid river, sediment deposition is common in this area. The change of the foundation of Achiba Bridge clearly shows an astonishing rate of sediment deposition (see Fig. 3). It is worthwhile to build a DTM of the debris fan annually to observe the change in elevation.

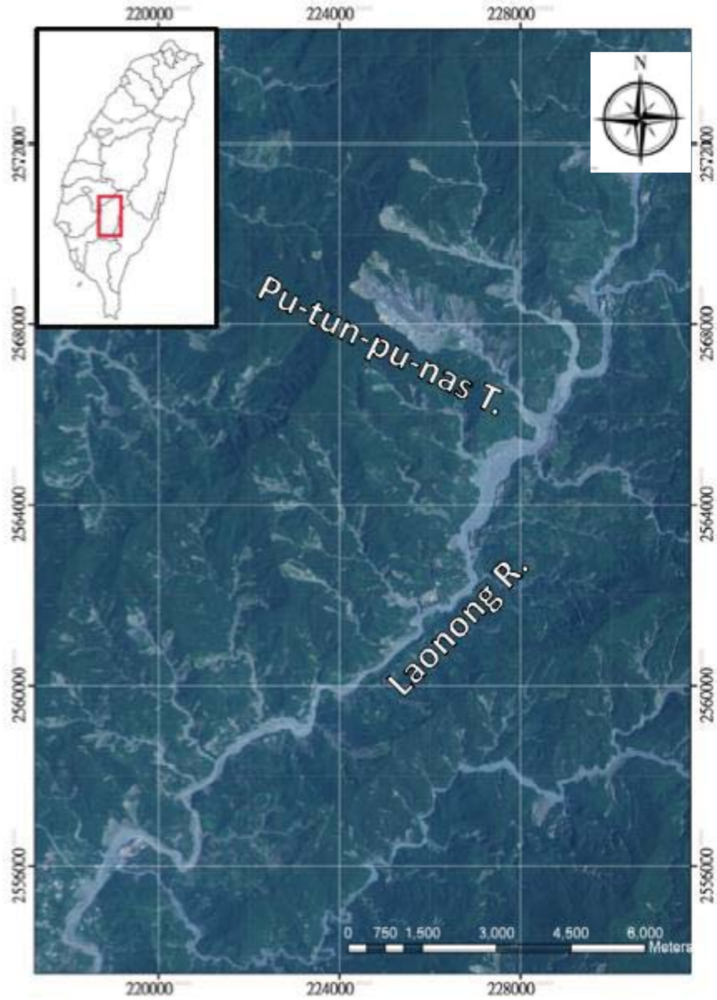

Fig. 2. The debris fan located at the intersection of Pun-tun-pu-nas tributary and Laonong River in Kaohsiung, south of Taiwan.

Fig. 3. The debris has risen 36.5 m between 2009 and 2012.

UAV Hardware

Since flying in the field requires durability and portability, a six-propeller UAV was utilized in this study. Our hexacopter UAV consists of three major components: a frame, controller, and camera.
The frame consists of six cylinder tubes, one base plate, and a gimbal. The whole structure is made of carbon fiber since it is both strong and light. The aircraft is equipped with 4014 brushless motors. A plate is used to place the controller, sensors, and batteries. Further, a two-axis gimbal is used to stabilize and control the direction of the camera (see Fig. 4).
The applied UAV controller system is based on DJI, a company that develops unmanned aerial systems (UAS). In the controller, there are some sensors, such as a GPS, barometer, gyroscope, and a 2.4 GHz radio control receiver. The positioning error of the GPS sensor is within 0.8 m in the vertical direction and 2.5 m in the horizontal direction.
In the system, a digital camera is utilized for transferring the images back to the ground. After considering the loading weight and photo quality, a Sony NEX-5R with a 16 mm F2.8 camera lens was selected (see Table 1).

Using this specification, the UAV can remain in the air for 20 minutes at a time. Furthermore, the horizontal communication distance is at least 1000 m.

Fig. 4. The multi-rotor UAV system used includes the aircraft, sensors, and a remote control.

Table 1: The hardware list of the UAV used

Component	Specification
Aircraft	**Tarot 680c** - 680 mm in diameter - composed of carbon fiber - 6 propellers can be installed **Propeller** - Tarot RC carbon fiber props 15 x 5.5
Motor	**SunnySky X4108S** - 600 KV (rpm/v) - Input Voltage: 2-6 cells lithium battery
Battery	**Li-ion Power** - 5200 mAh capacity (parallel connection) - 4S1P / 4 cells / 14.8 V - 30C constant discharge
Flight controller	**DJI NAZA-M V2** - 400 Hz refresh frequency - 1.5 W (0.3A@5V) max power consumption - 0.6 W (0.3A@5V) normal power consumption
Speed controller	**Hobbywing FlyFun-40A** - Continuous 40A output current - 50 Hz to 432 Hz refresh rate of the throttle signal
Gimbal controller	**The BaseCam Electronics 2-axis Gimbal Controller**
Camera	**Sony NEX-5R w/ SEL16F28** - 16.1 million pixels APS-C sensor - Up to 1920*1080p 60fps video stream - 16 mm (35 mm equiv. = 24 mm) focal length f/2.8 to f/22 aperture adjustment.
Image transmitter	**iFlight TX52W Image Transmitter** - 5.8 GHz Radio Frequency - 2000 mW (33dB±1dB) output power - 8 channels
Radio system	**Futaba 14SG 2.4GHz Computer Radio System** - 2.4 GHz Radio Frequency - 14 channels.

Goal

In this study, we wanted to verify that a UAV is indeed a timesaving and low-cost tool to acquire the required data for DTM reconstruction. There are two main approaches to collect the data for the DTM, namely by using LIDAR to obtain the point cloud of the terrain or using imagery from a satellite. However, both approaches cost time and money. In this research, we utilized a UAV as an image acquisition platform. By building the DTM of a debris fan using a traditional field survey, UAV system, and image-based modeling technology, we compared the accuracy with the time spent to gauge the results of each method and evaluate the feasibility of using a UAV for DTM reconstruction.

Methodology

We conducted the field test in three stages: image acquisition, field survey, and post processing.

Image Acquisition

Firstly, we used Google Earth's aerial photographs to divide the whole debris fan into seven chunks as shown in Fig. 5. Before the UAV took off, a detailed planned path was required to ensure that every area was covered. After path planning, a small, flat, and vacant location for use as a launching site was identified. We then setup our ground station, which consisted of an electricity generator, a laptop, and tools for adjusting the aircraft.

There were three people involved in every flight, namely one pilot, one assistant, and one person acting as ground crew. The pilot was in charge of controlling the aircraft and taking pictures. The assistant observed and recorded the state of the UAV and ensured that it followed the planned path. Meanwhile, the ground crew charged the used batteries and backed up all the images taken from each flight.

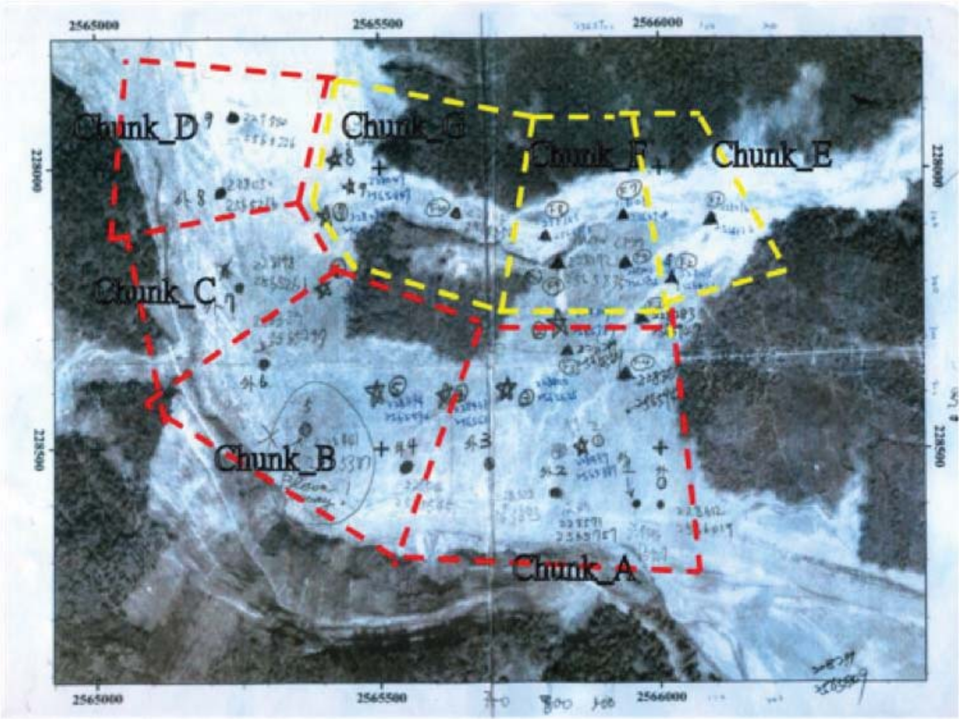

Fig. 5. The debris fan was divided into seven chunks (Chunk A - G).

Field Survey

To obtain the real world coordinates, we set up ground control points (GCPs) in each chunk. The total station was then used to measure the relative position of each point; the GPS sensor was used to obtain the absolute position in the world coordinate system. In order to ensure that the GCP were recognizable for post processing in the aerial photograph, we designed a marker, which was 1 m in length, 0.6 m in width, and had a circle with a diameter of 0.6 m painted black in the center. In addition, a disk was placed in the center of the black paint so that we could easily define the correct point in the photos (see Fig. 6). The markers were 3 to 5 pixels in the aerial photo, which was taken from a height of 300 m (see Fig. 7).

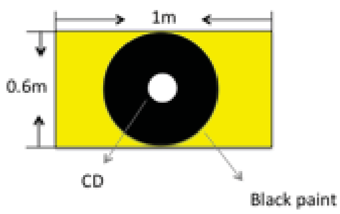

Fig. 6. The marker put on the debris fan was 1 m in length, 0.6 m in width, and had black paint in the center.

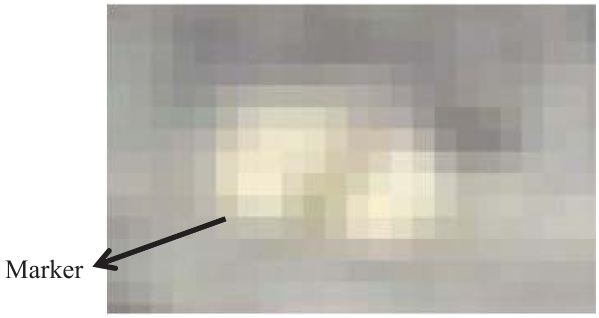

Fig. 7. The markers in the aerial photos were only 3 to 5 pixels.

Post Processing

There were 1085 photographs collected in the field for post processing. A visual selection of the photographs was made based on quality, viewing angle, and overlap for further analysis, i.e., blurred images and under- or overexposed images were removed from further processing, resulting in 314 photographs remaining from the flight task.

After visual filtering, the selected images were imported into commercial software, PhotoScan, which automatically estimates camera calibration parameters. In other words, there is no need to manually run a pre-calibration procedure. The photos were aligned and the marker coordinates were added in order for the software to perform optimization on them. After optimization, a dense point cloud was built. Finally, it textured the mesh and checked the error.

Results and Discussion

The result showed a complete DTM of the Pu-Tun-Pu-Nus debris fan. Errors of the result were estimated to be 0.1 m within 27 GCP. The DTM of the debris fan was composed of the separated results of seven chunks. Chunk A had errors estimated to be 0.05 m within 7 GCPs; Chunk B had errors estimated to be 0.08 m within 5 GCP; Chunk D had errors estimated to be 0.07 m within 2 GCP; Chunk E had errors estimated to be 0.09 m within 2 GCP; Chunk F had errors estimated to be 0.10 m within 4 GCP; and Chunk G's errors were estimated to be 5.8 cm within 4 GCP. The resolution of the complete DTM of the debris fan I was 0.28 m. This indicates that each pixel in the model was as long as 0.28 m in the real world coordinate system.

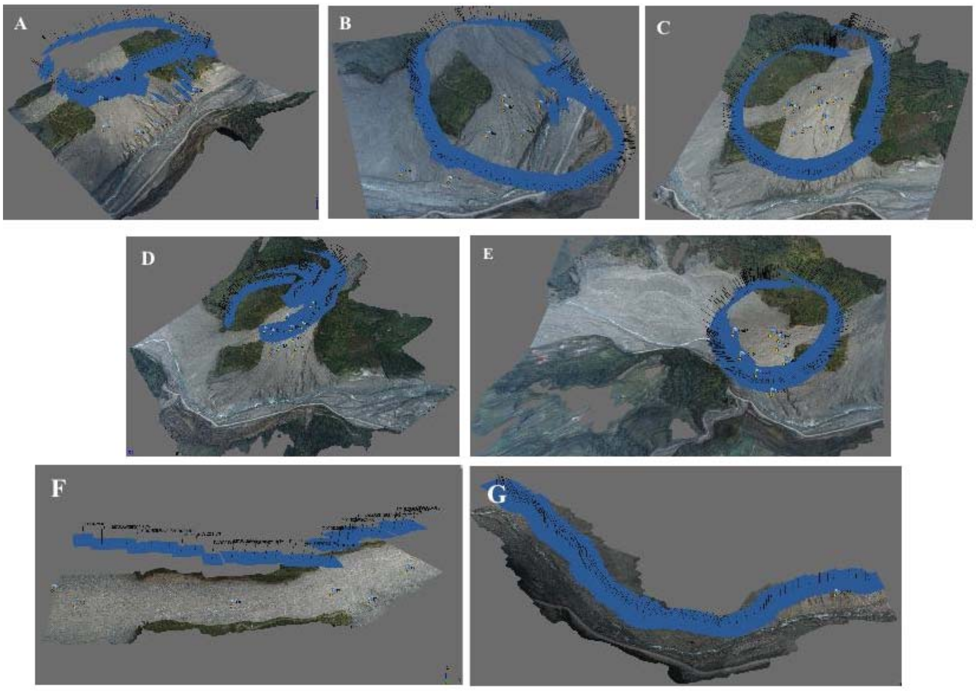

Fig. 8. Images A-G represent the DTM of Chunks A-G, respectively.

(The blue blocks on each model are the resolved 3D camera positions.)

The entire DTM reconstruction took approximately two weeks. It included three days of data collection and ten days of model construction. The results showed that using a UAV to assist with DTM reconstruction uses less time and labor. However, there are still points that require revision. For instance, the color of the marker could be chosen to be much brighter. Since the markers only cover 3 to 5 pixels in 16 million pixels, it can be much easier to track the marker if the color is brighter. A well-designed ground station can also improve time efficiency. Due to the steep terrain, a large amount of time was spent in setting up the ground station. If a mobile ground station, swhich can be setup in few minutes, is used, we can enhance the pre-procedure through saving time.

CONCLUSION

This study aims to develop an approach to assist with DTM reconstruction. We take a debris fan, Pu-tun-pu-nas, which is located in Kaohsiung, Taiwan, as a case study. The results show that using a UAV for DTM reconstruction can be as accurate as 10 cm. It took only three days to acquire the data and two weeks to construct the DTM. Comparison with other approaches such as LIDAR or satellite images shows that utilizing a UAV system for DTM reconstruction is a more affordable method that takes less time and cost but still has an accuracy of up to 10 cm.

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VISUALIZATION OF INSPECTION RESULTS OF CONCRETE BRIDGES USING REMOTE SENSING AND ARCGIS[1]

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ABSTRACT: *Current practices in bridge inspection cause traffic disruption and lane closure, and suffer from an incomplete visualization of defects and distresses. Research presented in this paper investigates potential use of remote sensing technologies in bridge inspection and highlights the added advantages of integrating ArcGIS with two remote sensing technologies; namely, Thermal Infrared (IR) and Ground Penetrating Radar (GPR) to provide visualization capabilities of captured inspection data. The integration of these technologies aims toward enhancing current practices in bridge inspection through: 1) Minimizing traffic disruption as remote sensing acquires data from a distance, 2) Improving representation and visualization of the condition state of inspected bridges. The proposed method will integrate IR and GPR and presents them in ArcGIS. Preliminary data analyses demonstrate the initial attractive features of the proposed system in enhancing current inspection practices of concrete bridges.*

KEYWORDS: *ArcGIS, Thermal Infrared IR, Ground Penetrating Radar GPR, Geographic Information System GIS, Remote sensing technologies, Bridge inspection, Bridge condition assessment.*

❖ INTRODUCTION

Bridge infrastructure in North America is in bad condition. Large number of national bridges in the US and Canada are defective due to several causes such as aging, environmental effects, excessive usage, and other factors. It has been stated in the literature that almost 25% of the bridges in the US are either structurally deficient or obsolete (NBI 2012). In Canada, around 8% were completely rebuilt in the past 7 years, while almost 15% of them are more than 50 years old (Transport Canada 2012). As a result, departments of transportation in the US and Canada are implementing Bridge Management Systems (BMS). BMSs are essential to manage bridges condition and arrange the applications of maintenance and rehabilitation actions in order to avoid complete failure and catastrophic events. Condition assessment is one of the objectives of any BMS. Bridge inspection is one of the early actions that should be performed towards a complete bridge condition assessment.
Currently, bridge inspection is being performed by visual inspection. Visual inspection is the process of assessing the condition of a bridge using simple equipment such as hammers and chains. These simple techniques are used to determine boundaries of delamination in the concrete subsurface. Differentiating sound changes is the basic principle in the application of hammer sound test or chain drag test. In both tests, the inspector will tap a hammer or drag a chain on top of the surface of the bridge deck. By noting for sound changes, delaminated areas could be identified (FHWA 2012). In some cases, a bridge inspector can recommend using other advanced techniques such as Non-Destructive Testing (NDT). Such techniques are advanced and they include Half-Cell Potential, Impact Echo, Ultrasonic Pulse Echo, Impulse response, Electrical resistivity … etc. (Gucunski et al. 2013).
Visual inspection and NDT techniques suffer from various limitations; the common limitations are that they cause traffic distribution and lane closure (Vaghefi et al. 2012). Another drawback is that they do not provide the bridge

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engineer with a complete visualization of the bridge condition although some NDT techniques are image-based. The Ontario Structural Inspection Manual (OSIM 2000) stated, "If an element is not completely visible, or the view is obstructed, quantities should be estimated and the "Limited Inspection" box should be checked on the form". That means only visible areas of the bridge are inspected which in result will yield to a less comprehensive condition assessment. Therefore, considering the use of remote sensing technologies that do not require direct contact with the object would minimize traffic disruption and will inspect inaccessible parts of the bridge. Furthermore, implementing such technologies such as Thermal Infrared (IR) and Ground Penetrating Radar (GPR) integrated with software such as ArcGIS will be an attempt to come up with more detailed inspection reports that mimic the condition of the bridge and give a better visualization based on the inspection data provided and the images captured.

REMOTE SENSING TECHNOLOGIES

As the current practice suffers from the previously mentioned limitations, considering other technologies in integration with state-of-the-art software would pave the way to more detailed inspection reports that reflect bridge conditions. Other technologies can be named as remote sensing technologies. Remote sensing is the process of collecting, measuring, and interpreting spatial information of an object from a distance (Sabins 1986, Ahlborn et al. 2010). The main advantage of utilizing such technologies is the capability of acquiring data from a distance without the need for a physical contact with the inspected object, thus minimizing traffic disruption can be achieved. Several remote sensing technologies can be used for concrete bridge condition assessment (Vaghefi et al. 2012). A comparative study of remote sensing technologies for concrete bridge condition assessment has been done by Yaghi et al. 2014. The model was developed to suggest the best remote sensing technologies to be used based on project objectives and end-user preferences. This paper is continuing the work and is suggesting utilizing Thermal Infrared (IR) alongside with Ground Penetrating Radar (GPR).

PROPOSED METHODOLOGY

The methodology aims toward integrating data collected by two remote sensing technologies, namely, Thermal Infrared and Ground Penetrating Radar. Data collection processes from these technologies are discussed below. The outputs from these technologies are input into ArcGIS. ArcGIS is used to present the results. The final results produced will be maps of detected defects that are geo-referenced. This has the potential to increase the understanding and visualization of the condition of bridges, and give the bridge engineer more sense of the condition of the bridge when compared to reading reports.

Thermal IR

ASTM D4788-03 2003 describes the test method, the environmental conditions, and the equipment needed to detect subsurface defects. To implement this procedure, a grid on the inspected area should be pre-defined. This grid specifies a certain area to be covered in each thermal image. This procedure will facilitate the process of building the thermograph map of the inspected bridge as edges of each image are defined and numbered in the grid. The edges of each square in the grid will be specified on the surface of the inspected bridge as well. A thermal image will be taken covering the area bounded by the edges of each square. The numbers are used to reference each image to its associated location on the ground. Therefore, a thermograph map can be built by joining the edges of each image on its corresponding location. Defining such areas will ease the process of importing the map into ArcGIS and define its coordinates. Regular images will also be taken covering the same areas that IR images cover. The regular images will help in building a regular map of the bridge to be imported to ArcGIS later on. Fig. 13 is an example where it shows that a high temperature area in the thermal image might reflect a delaminated area. Thermal and regular images such in Fig. 13 were taken on a bridge in the city of Laval, Montreal, Quebec, Canada as part of a case study for this research.

After studying the IR images, all the images will be linked together. The edges of each area shown in the IR picture will be joined together to form the thermograph map. The thermograph map will consist of series of thermal images placed next to each other based on the edges of each area and their numbers specified in the grid. Next, all the areas that show high temperature and can be a potential delamination will be marked on top of the map. Therefore, such locations of high temperature will be corresponding to their actual locations on the bridge deck. Fig. 14 shows a hypothetical example of a 4x5 grid of images. The red splines are drawn to refer to the hypothetical locations of potential delamination.

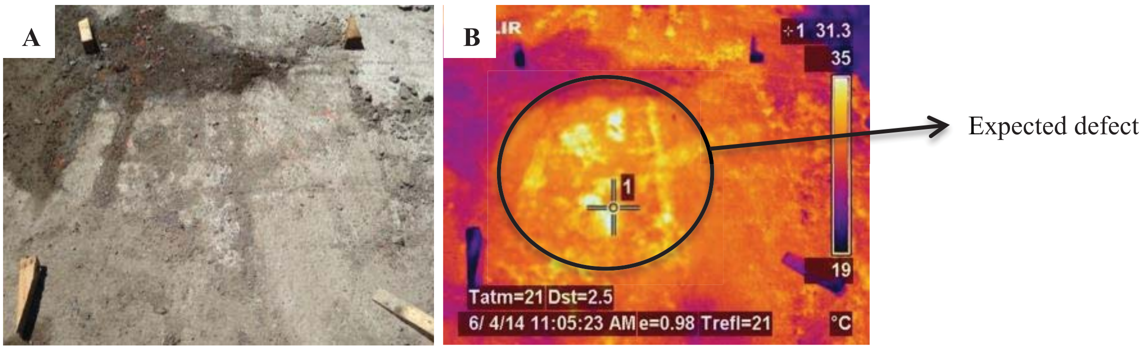

Fig. 13 Wooden pieces defines boundaries for each squared area

Ground Penetrating Radar

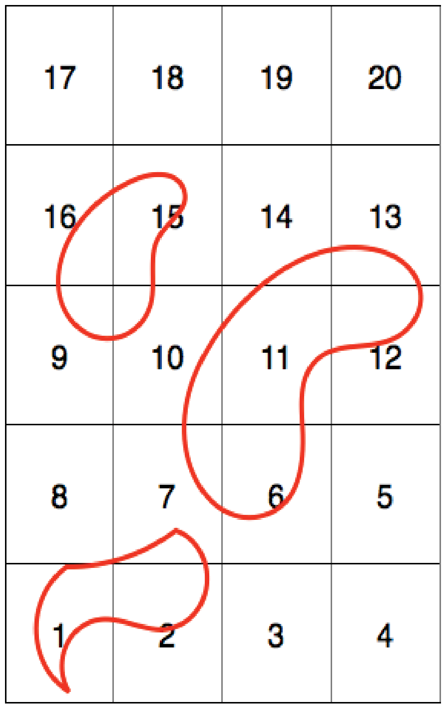

Fig. 14 A 4x5 grid for thermal images with hypothetical areas of high temperature

The first step in implementing GPR is also by pre-defining the grid for the GPR scans. GPR grid is different than the IR grid. The GPR grid consists of lines that define the paths at which each GPR pass will go through. This grid will help in producing the GPR results map later on by linking each pass with its correspondent line in the grid. After that, the bridge will be scanned. The GPR machine will be used to scan all the passes as prescribed in the grid. GPR already uses global positioning system (GPS) for coordinates, thus, a procedure for this task is not required. Fig. 15 is a typical GPR pass result that was also retrieved from the same bridge in the city of Laval. The red rectangles are manually added to define locations of signal attenuation that might refer to delamination. The distance of the expected delamination from the edge of the pass is shown in the figure. The same procedure of defining rectangles will be repeated on all the rest of the passes. As a result, locations of all the expected defects will be known. Extracting those locations and highlighting them on the GPR grid will be an easy task, as shown in Fig. 16 a hypothetical case where the locations of signal attenuations are highlighted on the GPR grid map.

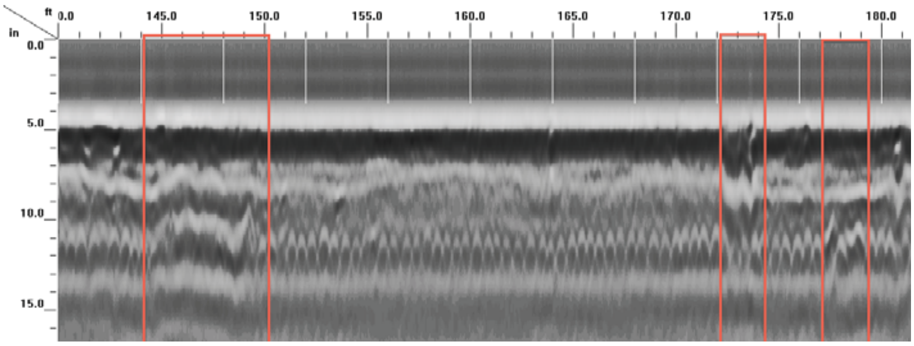

Fig. 15 A GPR scan profile

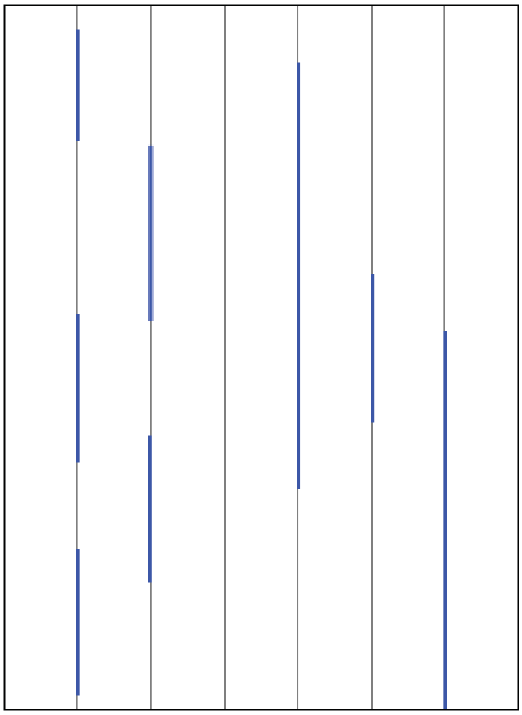

Fig. 16 Hypothetical highlighted GPR grid

ArcGIS

ArcGIS is a software product from ESRI (Environmental Systems Research Institute, Inc.) for the Geographic Information System (GIS). GIS was basically made up to replace the old way of studying the world from maps and globes into a more sophisticated computer system. GIS is the collection of all the maps, globes, and computer models along with tools for data analysis. GIS lets the user study every possible map with a lot of information such as land, elevation, climate zone, population density, per capita income… etc. A GIS map is made of layers that contain all the information. Layers could be oceans, countries, cities, rivers, lakes…etc. Each layer may contain features. For instance, the cities layer contains several cities; each city is called a feature. Features in GIS have different properties; they have surfaces, sizes, numeric values, locations, linked to information…etc. (Ormsby 2009).

Based on that, inspection report visualization can be enhanced by introducing ArcGIS software for reporting. ArcGIS is software used to create and share interactive maps. Several layers can be inputted to include all the inspection data provided. Such layers can vary; they can be map for the inspected bridge, maps of the results of each technology, any additional map from more technologies if needed. Those layers are used to illustrate the information as visual maps of results. In addition, several users can lively update each report over the Internet. Fig. 17 shows the hypothetical example results in ArcGIS.

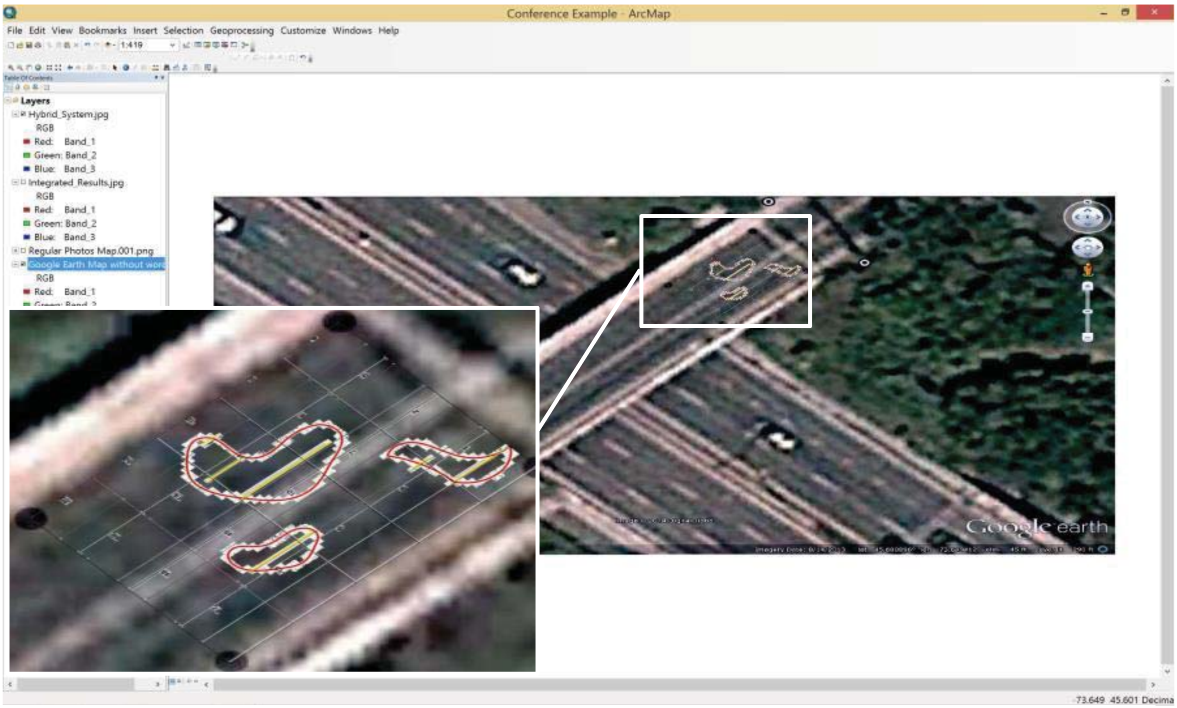

Fig. 17 Hypothetical example in ArcGIS

CONCLUSION

This paper presented integrated remote sensing system in an effort to advance current practice in concrete bridge condition assessment. The developed system has two advantages. One is collecting inspection data from a distance, which helps reducing traffic disruption caused by lane closures while inspecting bridges. The other advantage is providing visualization capabilities of the captured inspection data by utilizing ArcGIS for data representation and sharing. Inspection results are shown in maps instead of describing them by words. ArcGIS can represent the results of each technology by selecting its corresponding layer, and can present the overall condition by selecting all the layers. In addition, ArcGIS can be used as a complete reporting system, as information regarding the inspection can be assigned for every layer. Further, several users can lively update ArcGIS reports over the Internet.

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ASSISTING POST-EARTHQUAKE RECONSTRUCTION THROUGH INFORMATION VISUALIZATION USING GIS[1]

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ABSTRACT: *GIS, which enables integrated analysis of various elements such as town planning, industry, and public and disaster prevention facilities, can serve as an extremely effective tool in reconstruction following the Great East Japan Earthquake. However, the effective use of GIS analysis results requires the visualization of information such that any user can easily share images of reconstruction plans.*

Given this, this study focused on Google Maps and Google Earth. Its aim was the parallel use of GIS software and Google Maps, through KML data sharing with disaster-affected municipalities. It also visualized, using Google Earth, results of analysis conducted using GIS software, by converting these to KML. Finally, it aimed to assist post-earthquake reconstruction efforts by displaying reconstruction plans and disaster prevention information of the town of Yamamoto in Miyagi Prefecture with Google Earth.

KEYWORDS: *GIS, Assisting post-earthquake reconstruction, Google maps, Google earth, kml*

❖ INTRODUCTION

The tsunami resulting from the Great East Japan Earthquake, which took place on March 11, 2011, caused enormous damage to the Pacific coastal areas of the Tohoku region. Although lifelines have been for the most part restored, calls are being made for the swift progress of reconstruction efforts, from town planning to the state of agriculture, forestry, fisheries, commerce, and the manufacturing industry, and installation of disaster prevention and other public facilities (Miyagi Prefecture 2013).

Given this, utilizing GIS could prove extremely effective. GIS allows the integrated analysis of various elements mapped geographically. The advanced spatial analytical capacity of GIS can also be used in the consideration of a range of spatial information such as inundation range and the location of high ground (Shibasaki 2009, Japanese Geotechnical Society 2007).

However, there is currently no educational agency or materials set up for the systematic teaching of GIS concepts and system use, and there is a shortage of technical experts. There is also the fact that GIS software is relatively costly. Thus, GIS is not being effectively used by disaster-affected municipalities. Moreover, the effective use of the results of GIS analysis requires the visualization of information such that any user can easily share images of reconstruction plans.

For these reasons, this study focused on the freely available mapping software Google Maps and Google Earth. It aimed at the parallel use of GIS software and Google Maps, through keyhole markup language (KML) data sharing with disaster-affected municipalities. It also visualized, using Google Earth, results of analysis conducted using GIS software by converting these to KML. Finally, it aimed to assist post-earthquake reconstruction efforts by displaying with Google Earth reconstruction plans and disaster prevention information of the town of Yamamoto in Miyagi Prefecture.

SUPPORT FOR DISASTER-AFFECTED MUNICIPALITIES USING GIS

Designing support for disaster affected municipalities using GIS

Using KML data

In addition to being freely available, Google Maps is easy to learn to operate even without technical GIS skills, allowing any user to easily access spatial images. The software displays markers, images, polygons, three-dimensional models and explanations using data in KML format (Svennerberg 2010).

KML is an XML-based markup language developed for managing display of three-dimensional geospatial information in application programs, and has a similar syntactic structure to Geography Markup Language (GML). In addition to longitudinal and latitudinal information, KML can also record more detailed data required to construct camera views, such as tilt, camera angle, and height. Figure 1 shows an example of KML data.

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[1] Citation: Monobe, K. & Tokunaga, Y. (2014). Assisting post-earthquake reconstruction through information visualization using GIS. In: N. Dawood and S. Alkass (Eds.), Proceedings of the 14th International Conference on Construction Applications of Virtual Reality, 16-18 November 2014, Sharjah, UAE.

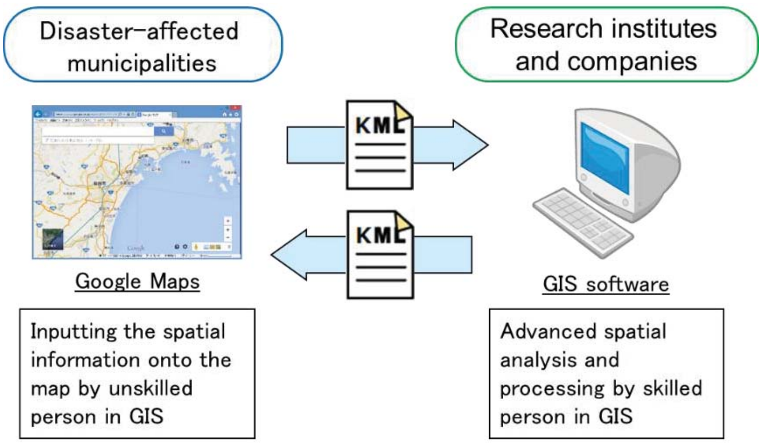
KML can be input and output not only using Google services such as Google Maps and Google Mobile, but also with commercially available GIS software (Wernecke 2008). Thus, KML allows the parallel use of GIS software and Google Maps.

Fig. 1: An example of KML data

Parallel use of GIS software and Google Maps

When municipalities collaborate with companies, universities and other research institutes using GIS software and encounter difficulty using the software, they end up giving instructions with hand-written maps and exchanging information orally and via email instead, creating unnecessary work.
To address this, municipalities can use Google Maps to input the required information onto the map, output that as KML data, and send this data to research institutes and companies that are able to use GIS software. Then, research institutes and companies can load the KML data to the GIS software and conduct advanced spatial analysis and processing that cannot be done using Google Maps. Finally, the analyzed spatial data is again output as KML data so that it can be examined by municipalities using Google Maps. Figure 2 illustrates this parallel use.

Fig. 2: Parallel use of GIS software and Google Maps



Implementing support for disaster-affected municipalities using GIS

Overview of plans for town-run bus routes

The 2011 tsunami has drastically changed residential areas in the town of Yamamoto, with houses being washed away, and temporary housing being installed. With this came the need to change the town-run bus routes. This required the use of GIS for integrated spatial analysis of housing and age distribution in residential areas, and the search for optimal routes. Thus, the town of Yamamoto collaborated with Miyagi University to plan new routes through the parallel use of GIS software and Google Maps. Figure 3 shows the town-run bus, the Gururin.

Fig. 3: The town-run bus service, the Gururin

As the Yamamoto town government does not have any employees with GIS technical expertise, route planning was conducted using Google Maps. Google Maps was also used to accurately input the location of bus stops, which would have been difficult for researchers at the university to ascertain. This was then output from Google Maps as KML data and sent to Miyagi University via email. Meanwhile, researchers at the university input the received KML data into the GIS software ArcGIS, and conducted spatial analysis for route searching and thematic mapping. Figure 4 shows the KML data of bus stops input using Google Maps.

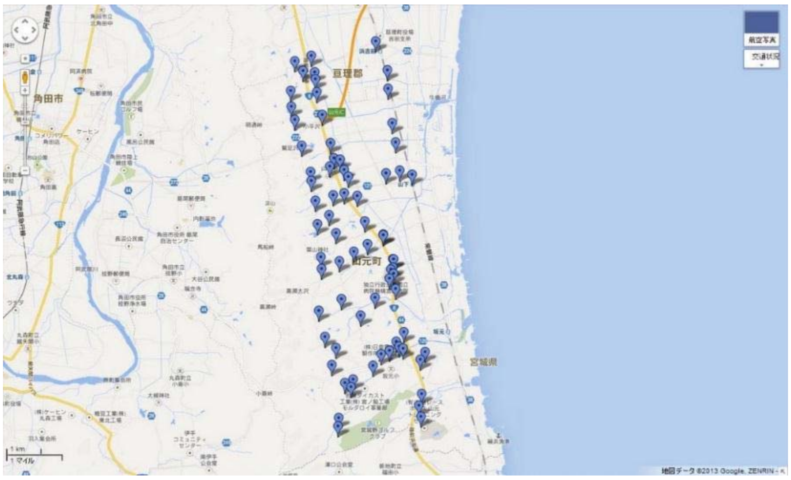


Fig. 4: Bus stop location information input using Google Maps

Preliminary survey for planning of the town-run bus routes

A preliminary survey was conducted ahead of the planning of routes for the town-run bus service. The survey method involved using Google Maps to input the accurate location of bus stops, representative points of each of the town's districts, and location of temporary housing and public facilities, which would have been difficult for researchers at Miyagi University to ascertain on their own. This data was then output as KML data and emailed to the university. Information about bus stops and passenger numbers on current bus routes, as well as age distribution in each district, were also sent to the researchers as Excel data via email.

Researchers at Miyagi University input the KML data and Excel data into ArcGIS, plotted bus routes, and displayed a graph of passenger numbers on the route map. Then population data for each of the districts and temporary housing establishments within Yamamoto, as well as information about shops and schools, was also displayed, and this was consolidated into data for use in route planning analysis. Passenger numbers on former bus routes are shown in Figure 5, and the age distribution in each district of Yamamoto is given in Figure 6.

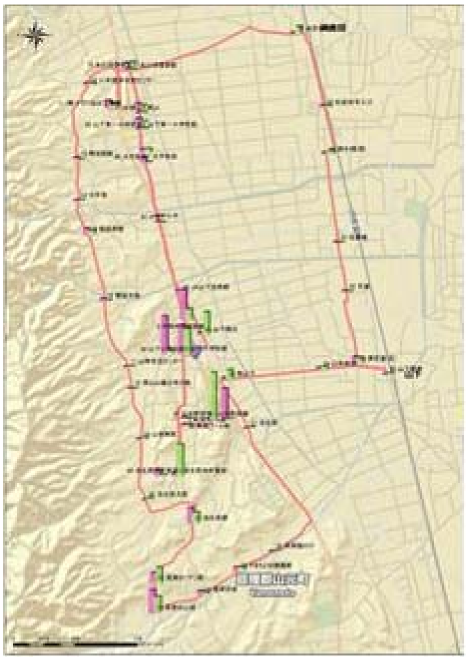


Fig. 5: Passenger numbers on former bus routes (average weekday)

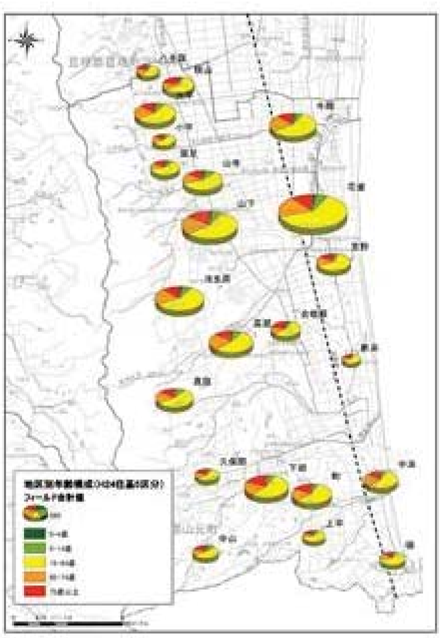


Fig. 6: Age distribution in each district in Yamamoto (registered residents in each district, 2012)

Analysis for town-run bus route plans

In addition to the information consolidated in the preliminary survey in preparation for route planning, tsunami inundation range and other information were displayed on ArcGIS and new route analysis was conducted. Using the analytical functions of GIS, new routes were planned taking into account such factors as whether roads passed by temporary housing establishments and other areas with large populations or large numbers of elderly people or children, whether roads passed by hospitals or schools, how to avoid to the greatest possible extent areas inundated by the tsunami, and minimizing distance for the most efficient route. For coastal areas with large populations, bus routes were set out with residents' convenience in mind, disregarding whether or not the area was within the range inundated by the tsunami.

Specifically, the GIS analysis method used was as follows. First, a road network was constructed based on the Digital Map 25000 published by the Geographical Survey Institute. Possible bus stop locations were set as network nodes, and given attribute data describing local district populations by age, surrounding facilities such as schools, hospitals and shops, as well as whether or not the location had been inundated by the tsunami. Attribute data was also given to the links between nodes, including information on distance and time taken to travel by foot. Then, the ArcGIS network analysis function was used to output possible optimal bus routes using weighting information based on the attributes of nodes and links. However, network analysis on its own makes it difficult to consider diagrams that require more technical knowledge, and therefore the expertise of a traffic engineer in relation to such diagrams were sought and incorporated into the route plans. The ArcGIS analysis including information on tsunami inundation range is given in Figure 7.

Based on the above analyses, new routes for the town-run bus service were determined. For the new routes, two time periods were proposed: a daytime period and a commuting time period (taking into account commutes to and from work, school for children, and hospitals for elderly passengers). Figure 8 shows the map of the town-run bus route plan for the commuting time period.

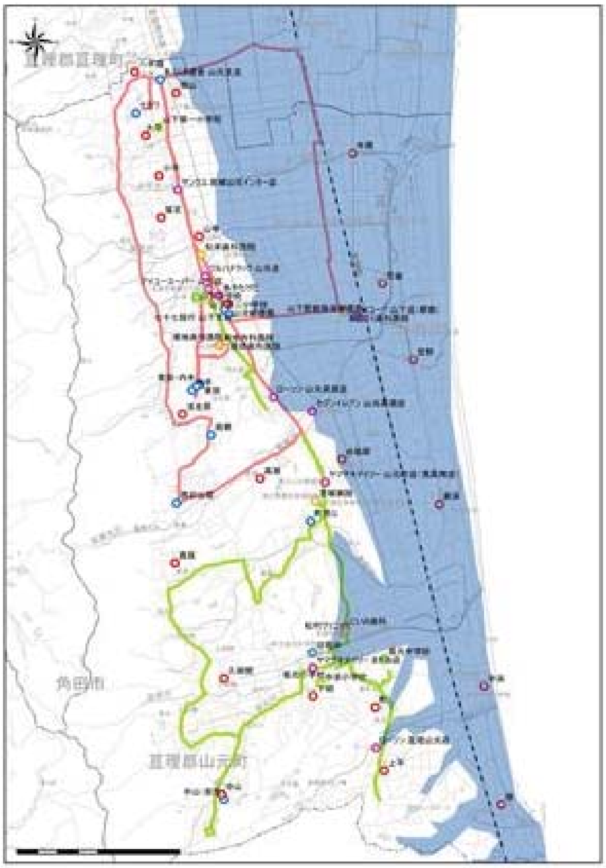


Fig. 7: Town-run bus route analysis (showing tsunami inundation range etc.)

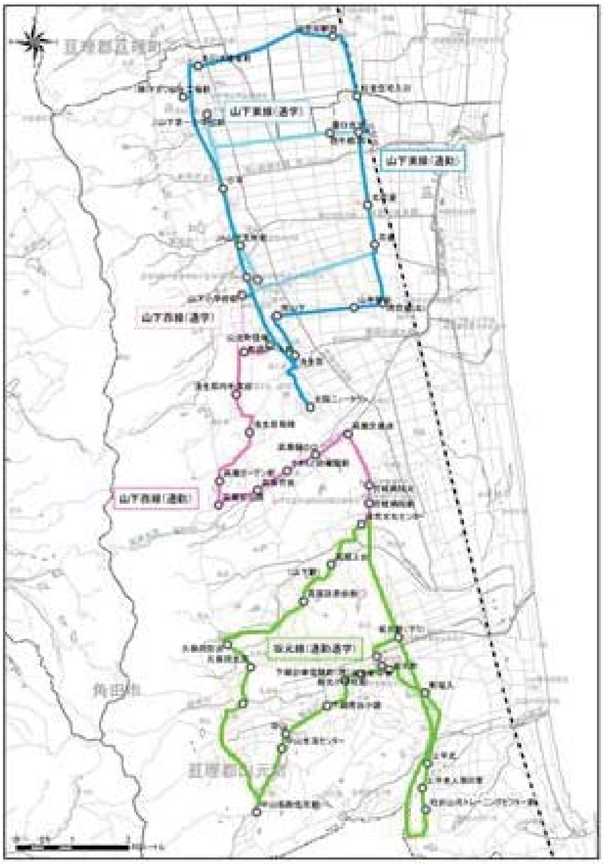


Fig. 8: Map of town-run bus route plan (school and work commute)

VISUALIZATION OF POST-EARTHQUAKE RECONSTRUCTION INFORMATION USING GIS

Visualization of information using Google Earth

Google Earth was used in order to visualize information created using GIS. Google Earth not only provides a free digital globe based on high resolution aerial photography, but it is also easy to operate even without technical knowledge of GIS. Moreover, because it is able to read KML data, it has the advantage of enabling the display of GIS analysis results by converting them to KML data.

Thus, visualization of the ArcGIS analysis results were converted to KML data and visualized using Google Earth. The study also aimed to use the Google Earth display of information on reconstruction plans and disaster prevention in Yamamoto to help support efforts for post-earthquake reconstruction.

The use of KML data allows the linkage of GIS software with Google Earth. Therefore, integration and analysis of spatial data, which is difficult for disaster-affected municipalities, can be conducted by research institutes and companies, and this can be output as data in KML format. The KML data is then loaded onto Google Earth and visualized, enabling the display of easy-to-understand images of reconstruction plans which would be difficult to produce using only GIS software. Furthermore, as Google Earth is easy to operate, residents themselves can use the software to check spatial information from a range of perspectives, and this assists the sharing of images of reconstruction plans with residents. Figure 9 is an image of visualization using KML and Google Earth.

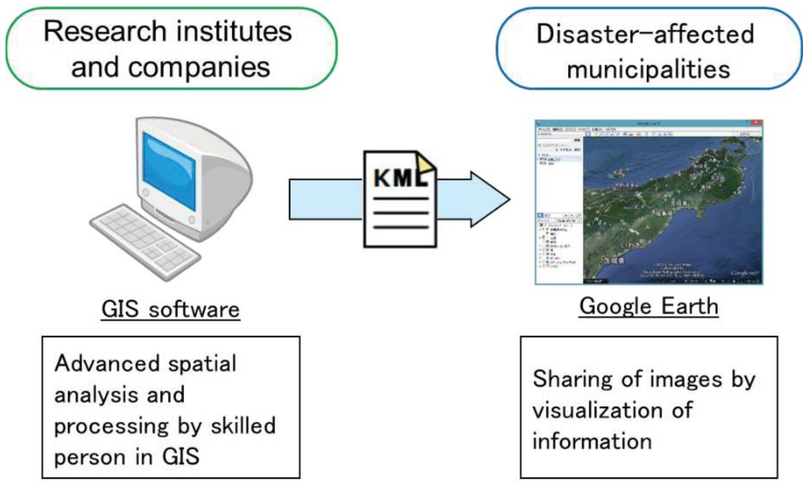


Fig. 9: Google Earth visualization using KML

Use of Google Earth by the town of Yamamoto

The 2011 tsunami drastically changed residential areas in Yamamoto, with houses being washed away, and temporary housing being installed. With this came the need to change the town-run bus route. Thus, as outlined in section 2, the town of Yamamoto and Miyagi University collaborated to plan new bus routes by conducting spatial analysis using GIS and engaging in parallel use of ArcGIS and Google Maps.

Following on from this, Google Earth was used to display the new routes for the town-run bus service. Displaying not only routes but also information about public offices, schools, hospitals and other facilities that exist on the routes helped enable the provision of information on bus routes to bus users.

Another aim of the display was to raise awareness about disaster prevention by visualizing the area inundated at the time of the tsunami. Furthermore, information was added on reconstruction and development plans and the location of temporary housing in order to support the sharing of images of reconstruction planning. The use of Google Earth to display photographs from the time of the tsunami as an archive of the disaster, and visualizing tourist information about Yamamoto to contribute to reconstruction efforts by attracting tourism, are also being considered. The remainder of this paper will explain the details of the content visualized using Google Earth.

Displaying town-run bus routes and en route facilities

The new routes for the town-run bus service were displayed using Google Earth. Using this software to display the bus routes enabled bus users to check the routes from various perspectives. Information was also provided to users about en route hospitals, schools, shops and other facilities. The facilities located on the town-run bus routes (daytime routes) are given in Figure 10.

Fig. 10: Town-run bus route (daytime) and en route facilities

Overlay of Yamamoto reconstruction plans

Figure 11 gives the result of overlaying the land use schematic for Yamamoto reconstruction plans (Town of Yamamoto in Miyagi Prefecture 2013) onto Google Earth. The overlay required revision of the schematic such that it could be laid on top of Google Earth. The land use schematic alone makes it difficult to see the plans for reconstruction in one's own neighborhood, but overlaying it onto Google Earth helps residents use their nearest bus stop as a marker and increase their understanding of reconstruction plans in their neighborhood. Figure 12 displays the result of overlaying the Yamamoto reconstruction plans and the bus routes.

Fig. 11: Overlay of Yamamoto reconstruction and development plan land use schematic

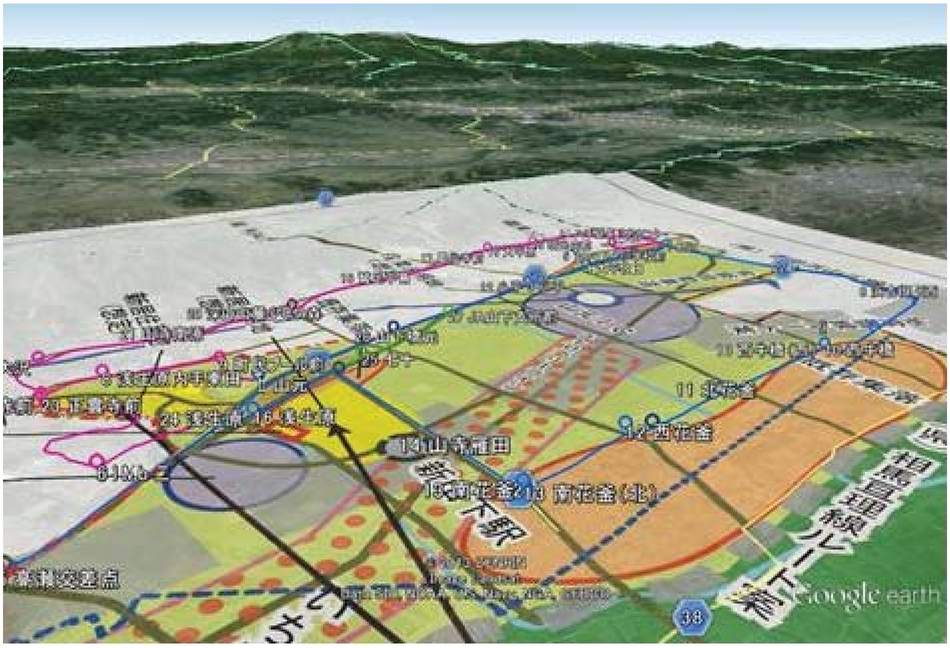


Fig. 12: Yamamoto reconstruction and development plans and bus routes

Utilization in disaster archiving

In addition to the display of the town-run bus service routes, the initiative was also given the function of a natural disaster archive. Since the Great East Japan Earthquake, a variety of geographical information relating to the disaster has been published. Tsunami inundation area data from one such resource, the Great East Japan Earthquake and Tsunami Local Field Survey Report (Japan Society of Geoinformatics 2013), was displayed using Google Earth. Displaying the tsunami inundation area on Google Earth and adding this to the bus routes enables the more intuitive understanding of the scope of the inundation caused by the tsunami. The result of overlaying the tsunami inundation area in the town of Yamamoto with the bus routes is given in Figure 13.
Google Earth was also used to display photographs from the time of the disaster. Through combination of photograph locations and angles, users can gain the virtual experience of actually seeing the aftermath. Figure 14 shows the result of using Google Earth to display a photograph of JR Sakamoto Station taken on June 2, 2011.

Fig. 13: Overlay of Yamamoto tsunami inundation range and bus routes

Fig. 14: A photograph of tsunami aftermath displayed on Google Earth
(taken at JR Sakamoto Station, June 2, 2011)

Application in supporting the provision of tourism information

Because increasing numbers of tourists is beneficial for post-disaster recovery, the initiative also sought to use Google Earth to assist in the provision of tourism information. Tourist attractions near bus stops were introduced to potential visitors, using bus routes displayed on Google Earth as the key information. By displaying this on Google Earth alongside actual photo-graphs of the locations, the town can be visited virtually.
As an example of the provision of tourism information, Figure 15 shows the result of adding photographs taken from Shinzan Peak, a tourist attraction near Shinzan Base Shonen No Mori bus stop, to Google Earth.

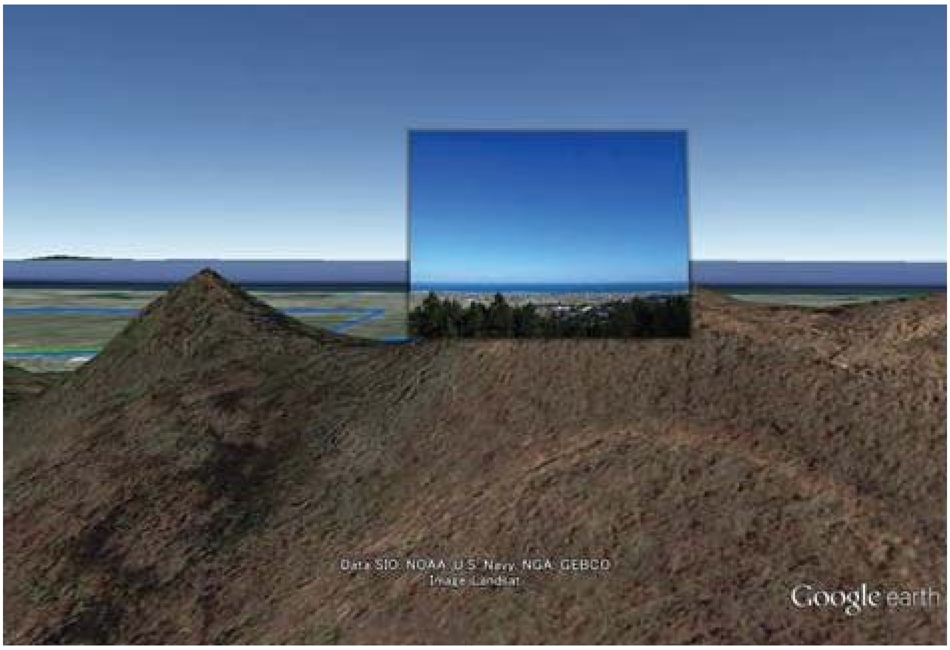


Fig. 15: Combination of a photograph from Shinzan Peak and Google Earth
(photograph taken November 3, 2012 from Shinzan Peak)

CONCLUSION

This study focused on the freely available mapping software Google Maps and Google Earth to design a KML-based post-disaster reconstruction support initiative. GIS software and Google Maps were successfully used in parallel and the study was able to increase the efficiency of GIS analysis through KML-based data sharing with disaster-affected municipalities. Converting results of analysis conducted using GIS software into KML, visualizing these with Google Earth, and displaying bus route and reconstruction plan information of the town of Yamamoto in Miyagi Prefecture using Google Earth, helped assist post-disaster reconstruction in the town.
However, as this study used email to share KML-based data, the issue remained of extra labor required for the sending and receiving of data. In addition, while Google Earth has the advantage of allowing free movement within virtual spaces, users also commented that they did not know where to focus their vision.
With regard to such issues in KML-based data sharing, in the future we aim to make this sharing more efficient by utilizing online data storage. We also plan to continue to provide GIS-based reconstruction support by making improvements such as increasing convenience for users through providing a large number of bookmarks of saved locations and perspectives on Google Earth.

ACKNOWLEDGEMENTS

Part of this study was funded by a 2011-2013 JACIC Research Grant (under the theme of ‘Research about earthquake reconstruction support by using GIS based on construction and utilization of a social infrastructure register') and by a 2011-2013 Grant-in-aid for Scientific Research (C) (under the theme of 'Research about regional public transport evaluation and system build processes based on a latent potential approach'). ArcGIS was provided by ESRI Japan Corporation through a GIS utilization support program for universities (under the theme of 'Research about the use of GIS in Great East Japan Earthquake post-disaster reconstruction support'). We would like to take this opportunity to express our gratitude to these organizations.

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PART IV: VISUALIZATION, SIMULATION & SUSTAINABILITY

INNER SURFACE MEASUREMENT WITH RGB-D CAMERA USING MULTIPLE LIGHT MARKERS[1]

Hiroki Inoue, Hiroshige Dan, Akira Kobayashi and Yoshihiro Yasumuro
Kansai University, Japan

ABSTRACT: *Many developed countries are facing problems resulting from decades-old infrastructures built in a period of rapid economic growth. Political strategies and maintenance schemes for reinforcement and repair of civil infrastructures have recently gathered more attention. Especially under the severe fiscal circumstances prevailing in aging societies, it is not realistic to deal with every deteriorated infrastructure facility throughout the country. Therefore, a systematic, minimum-cost solution is desired for finding and prioritizing critically deteriorated facilities to be upgraded. This paper focuses on pipelines for water supply, sewerage, and agricultural water use. Many of these pipelines are buried underground and thus investigating their distortion and deterioration is not easy without excavation. Furthermore, since excavation processes are intrusive to neighboring residents and traffic, it is important to carefully choose the investigation locations beforehand. The authors propose an investigation system with an RGB-D camera, which is a depth-imaging device, to examine the inside of pipelines. An RGB-D camera can collect not only the color imagery but also the 3D shape information from the inside of pipes. Taking advantage of the compact size of the RGB-D camera, we propose to construct a self-propelled system to scan a pipeline so that large-scale excavations are not necessary. This will lower costs and speed up investigations. This paper reports the efficiency of capturing dense shape data of a pipe-shaped object by an RGB-D camera with 1.5% error relative to the actual dimensions.*

KEYWORDS: *Pipeline investigation, Depth image, RGB-D camera, 3D shape, Distortion distribution*

❖ INTRODUCTION

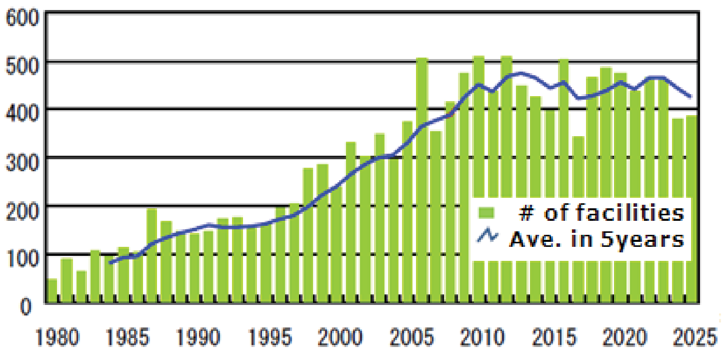


Fig. 1: Water pipeline facilities exceeding lifetime; expected yearly numbers (left) and photograph of a severely corrupted case (right)

Many developed countries are facing problems resulting from decades-old infrastructures built during a period of rapid economic growth. In Japan, for example, as shown in Fig. 1 (left), the water pipeline infrastructure is a typical decades-old infrastructure that has various uses, such as water supply, sewerage, and agricultural use. Many of these pipes are buried underground networks and the deterioration is difficult to identify before the damage becomes severe, as shown in Fig. 1 (right). Political strategies and maintenance schemes for reinforcement and repairing civil infrastructures have recently gathered more attention. Especially under the severe fiscal circumstances prevailing in aging societies, it is not realistic to deal with every deteriorated infrastructure facility throughout the country.

[1] Citation: Inoue, H., Dan, H., Kobayashi, A. & Yasumuro, Y. (2014). Inner surface measurement with RGB-D camera using multiple light markers. In: N. Dawood and S. Alkass (Eds.), Proceedings of the 14th International Conference on Construction Applications of Virtual Reality, 16-18 November 2014, Sharjah, UAE.

To maintain the structures and functionalities of existing pipelines, it is important to monitor and understand the conditions inside the pipes. The two major types of existing methods for investigating pipelines are indirect investigation from the ground surface and direct investigation of the pipe interior. Indirect investigation targets water leakage, flow volume and corrosion by sampling the water volume, electrical potential and soil materials at different points. Imaging the pipe interior conditions using a video camera is also one of the indirect investigations. For interior investigation, the inside wall of the pipeline can be examined and diagnosed by direct measurement with a depth gauge or by visual inspection. Direct investigation targets cracked conditions, snaking and/or sinking of pipelines, deflection, tube thickness, distances of couplings, rust and sediment conditions. Whereas the indirect investigations provide a macroscopic level of information of the characteristics of existing pipelines, direct investigations provide quantitative metrics of pipe configurations. However, direct investigations require an excavation process to expose the pipe structures for direct access and still depend on a discrete sampling approach. For example, the aspect ratio for deflection and the strain at cross-sections are checked at only specified intervals. In recent years, high-resolution camera devices can be installed on a self-propelled robot for remote control operation (Yamashita 2011). Color images are informative material for experienced operators, but quantitative metrics of the pipe characteristics are also required for objective investigation and management. Therefore, our purpose is to propose an objective and comprehensive approach for investigation of the inside of pipelines with a minimum excavation process.

PROPOSED METHOD

Depth Imaging by an RGB-D Camera

We employ an RGB-D camera that is capable of imaging depth information to capture the 3D shape of the inside wall of a pipeline. Many RGB-D cameras use an active stereo vision method for triangulation by using a pair of calibrated structured light sources and a camera. Presently, compact RGB-D camera devices are used for video game user-interfaces, which can capture depth images at a high frame rate for human motion capture (Freedman et al. 2010). Considering the dark condition inside pipes, sunlight or other light sources are not a problem. Therefore, the RGB-D camera is suitable for our purpose, unlike the existing range finders of laser scanning systems that have high precision but a slower capture rate.

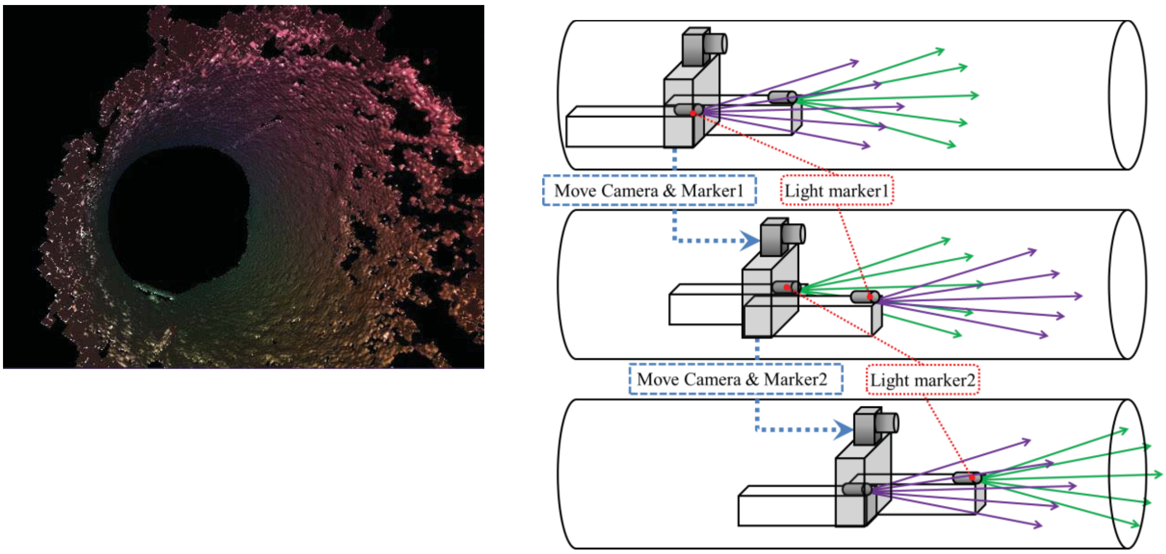


Fig. 3: The proposed strategy for integrating the 3D point cloud; using multiple light markers alternately as the camera sensor moves forward.

In our method, an RGB-D camera is installed on self-propelled wheeled equipment that can collect and transmit color and depth images with high-resolution texture images to a host computer in real time. Then, an image-based inspection and a distortion analysis can be conducted anytime by an operator. Our scheme consists of two steps: (1)

capturing the 3D shape information as a point cloud and mesh data set, (2) fitting an ideal pipe model and extracting the amount of deformation or the strain distribution along the inside surface of the pipe.

The RGB-D camera captures depth images at a video rate, and the data frames at each depth are accumulated in volumetric space to generate continuous smooth surfaces. This process is executed by the KinectFusion method (Newcombe et al. 2011), which is available as an open source implementation (Point Cloud Library) and in other commercial software products. A raw depth image is converted into a floating point depth set. Then the global or world camera poses, including the location and orientation, are calculated for iterative alignment in order to track a camera pose relative to the initial starting frame. The tracking process uses feature points or variations in each depth image to align the newly incoming depth maps. Finally, all depth data are fused into an identical volumetric space to integrate the continuous surface. The reconstruction volume for surface generation is made up of small cubes in space. These cubes are referred to as voxels. The sensor stays still at a single position, and the incoming depth maps for filling gaps or holes are aligned so that surfaces are continuously refined. As the camera moves closer to the physical surface, surfaces are refined with newer high-resolution data.

Distortion Inspection with Depth Images

By comparing each span of the point cloud acquired from a single viewpoint to the ideal cylinder surface, we can obtain the deflection distribution as the displacement along the inner surface of the actual pipe. We fit an ideal cylinder shape to the pipe-shaped point cloud data by using principal component analysis (PCA).

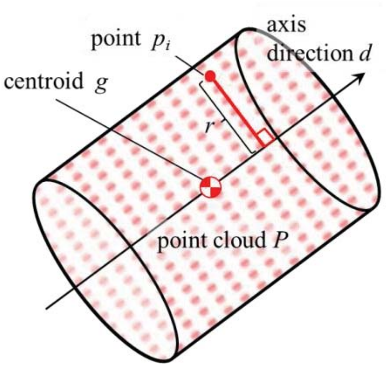


Fig. 4: PCA based radius estimation of the pipe-shaped point cloud data

We let g be the centroid of point cloud P at a single viewpoint. Point cloud P consists of 3D points p_i (i=1, …, N). The axis direction of the cylindrical shape of the point cloud is found as the first principal component of the covariance matrix, cov(P):

$\mathrm{cov}(P) = E[(\mathrm{P} - g)(\mathrm{P} - g)^T]$,

where g is the centroid of the point cloud segment. The first component is given as the eigenvector d with the largest eigenvalue of cov(P). Point c on the axis line is expressed by parameter t and normalized axis direction $\hat{d}$ as $c = g + t\hat{d}$. We use the distance from each point p_i in P to the axis line as a distortion metric. By comparing the nominal radius value of the pipe product specification, larger values can be colored as expansive strain and smaller values as compressive strain, for example (Yasumuro 2013).

Point Cloud Registration Based on Marking Texture

In our scenario using an RGB-D camera, the system is supposed to observe the monotonous smooth surface of the pipe unless uneven gaps or cracks or large deflections are found. Since the tracking process relies on natural feature points or variations of the inner surface shape of the pipe, the tracking process easily fails in most cases without eminent features. It is desired that the system automatically records the whole inner surface of the pipe situation by using high-resolution images as the camera moves forward, even when critical problems are not found, since visual inspection by the human operator and qualitative data collection of the inspection are possible. To assure the system can monitor its own position through the pipe inspection independent of the natural features of shapes or the colors of the target, we employ two light sources of different colors to put multiple marks on the inner surface of the pipe. The camera moves together with one of the two light markers while the other light marker is fixed. Then, alternately, the light markers are moved continuously forward with the camera. This procedure assures that the consecutive depth images share the identical light markers of different colors.

The pose estimation problem we must solve is registration of corresponding point sets X, Y, which are given by the light markers. Estimating a rigid body transformation (in particular, a rotation matrix) that gives the best match between X and Y is required. Estimating a rotation matrix is also required for using rotation matrices as the pose parameters of the three-degrees-of-freedom pose. We apply a method using singular value decomposition (SVD) (Arun 1987, Schönemman 1996). Two sets of 3D points of the detected light markers on the objects are expressed as $X = \{x_i\}_{i=1}^{n}$ and $Y = \{y_i\}_{i=1}^{n}$. Rigid body transformation defined with rotation R and translation t is written as follows:

$$y_i = Rx_i + t,$$

where x_i and y_i are the corresponding points of the 3D point sets X and Y. The transformation (R, t) can be found by minimizing the following objective function.

$$\min_{(R,t)\in SE(3)} \sum_{i=1}^{n} \|y_i - (Rx_i + t)\|^2$$

One of the easiest ways to estimate translation t is to use the translation between the centroids of X and Y. Let the centroids of X and Y *be* $\bar{x}$ and $\bar{y}$, respectively. The translated x_i and y_i are expressed as follows.

$$x_i' = x_i - \bar{x},\ y_i' = y_i - \bar{y}$$

Then, the rotation R can be found for fitting X and Y by minimizing the objective function below.

$$\min_{R\in SO(3)} \|Y' - RX'\|_F^2$$

The objective function can be rewritten as follows:

$$\|Y' - RX'\|_F^2 = tr((Y' - RX')^T(Y' - RX')) = tr\left(Y'^T Y'\right) + tr\left(X'^T X'\right) + 2tr\left(Y'^T RX'\right).$$

This objective function is equivalent to maximization of the following.

$$\max tr\left(Y'^T RX'\right)$$

Here, let the SVD of $X'Y'^T \in R^{3\times3}$ be $X'Y'^T = U\Sigma V^T$, where Σ is a 3x3 non-negative diagonal matrix, and U, V ∊O(3). Then the objective function can be transformed as follows:

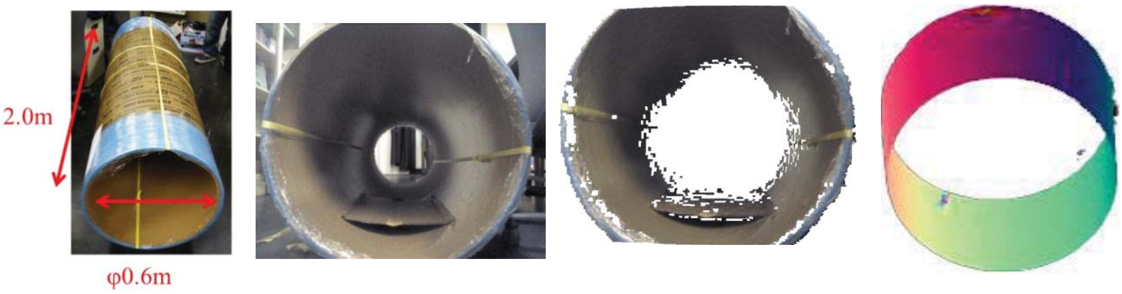
$$tr\left(Y'^T RX'\right) = \sum_{i=1}^{n} y_i'^T Ryx_i' = tr\left(RX'Y'^T\right) = tr(RU\Sigma V^T) = tr(V^T RU\Sigma).$$

If $V^T RU = I_3$, the objective function is maximized, and then $\hat{R} = V^T U$ is the desired rotation matrix.

Table 1: RGB-D Camera Specification

Device	Kinect™ for Xbox360	
Field of view	57 ° (H) x 43 ° (V)	
Depth image size	640 pix (W) x 480 pix (H)	
Depth range	0.8 ~ 4.0 m	
Frame rate	30 fps	

EXPERIMENT



(a) (b) (c) (d)

Fig. 4: Kinect shot of the inner surface of the pipe from a single viewpoint; (a) target void tube, (b) artificially added gap of the wall, (c) single viewpoint shot with Kinect, (d) colored expression of the deflection

We conducted an experiment to measure a pipe-shaped object by using a Kinect sensor (Microsoft Inc.). The specification is shown in Table 1. As an experimental measurement target, we prepared a void tube as a pipe-shaped object 0.6 m ϕ and 2.0 [m] long, as shown in Figure 5. Two laser emitters with 50 [mW] of power were used for the marker light sources of different colors. One was a green color (wavelength: 532 [nm]) and the other was a purple color (wavelength: 407 [nm]). We employed the software Artec Studio (Artec Group Inc.) for data collection with the Kinect sensor. The voxel grid size for accumulating the depth map was 1.2 [mm].

From a single viewpoint, we could acquire a continuous pipe-shaped point cloud and mesh data that contained up to 1M vertices and 10M faces. The artificially added inner wall gap was detected as shown in Fig. 4. The physical size of the gap was 45 [mm] and the recorded gap size was 43.4 [mm]. In the surface reconstruction process, by fusing every depth data into an identical voxel space for integration, denoising or smoothing may limit the high-frequency shape data. However, constant 10 [mm] order gaps and ditches can be detected, and thus the performance to find critical distortions was confirmed.

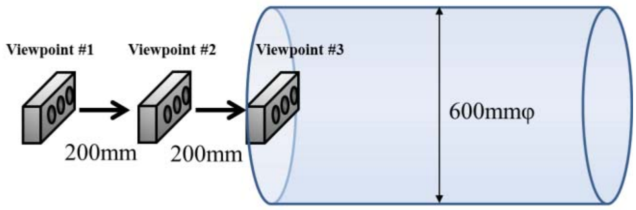
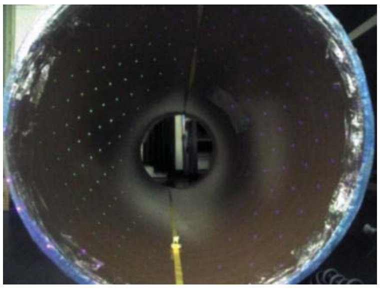
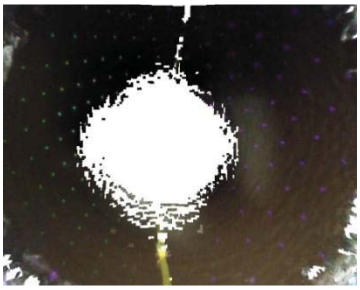


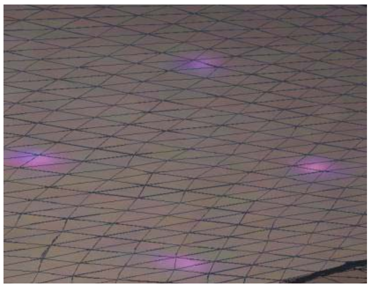
Fig. 5: Step-by-Step 3D imaging with RGB-D camera

As for registration of the point cloud sets acquired by different viewpoints, we performed the measurements as shown in Fig. 5. The Kinect sensor and the laser emitters were manually moved forward by 200 [mm] intervals, according to the step-by-step fashion shown in Fig. 3.

Fig. 6 (left) shows the light markers on the inner surface of the target and Fig. 6 (middle) shows a single viewpoint shot by the Kinect sensor. A close view of the reconstructed surface mesh with texture information is shown in Fig. 6 (right). We manually selected the marker spot areas of the meshes surface and averaged the 3D coordinates of the surrounding vertices, and thus the marker's 3D positions were recorded by sub-mesh resolutions. To select the pair of corresponding markers between data of different viewpoints, we applied RANSAC (RANdom SAmple Consensus) (Martin 1981), which iteratively estimates parameters of a mathematical model from a set of observed data containing outliers. The basic assumption is that the data consists of "inliers" whose distribution can be explained by the same transformation parameters to fit the pairs of marker positions, and "outliers" that do not fit the transformation. The outliers may come from extreme values of noise or from erroneous measurements. The numbers of selected light markers actually used for registration were 14 for viewpoints #1 and #2, and 9 for viewpoints #2 and #3, as shown in Fig. 7. The average error in fitting viewpoints #1 to #2 was 5.14 [mm] and the standard deviation was 2.38 [mm]. For fitting viewpoints #2 to #3, the average error was 4.89 [mm] and the standard deviation was 1.47 [mm].







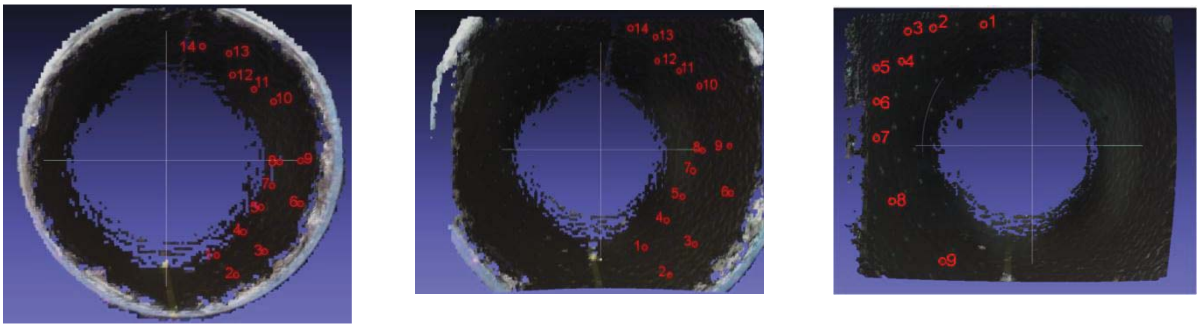


Fig. 7: Light markers with 2 different colors of laser pointers; Photo of physical sample (upper left), textured depth model (upper middle), and its surface details (upper right), Corresponding points of light markers: shots #1, #2 and #3 (lower, from left to the right)

CONCLUSIONS

This paper proposed a pipeline investigation system employing a depth imaging device for effective and efficient inspection of the interior wall of pipes. Based on a prototype implementation with a Kinect camera, the continuous surface shape and distribution of the distortion could be captured. The system configuration can be expected to provide quantitative inspections based on both the color imagery and the 3D shape information. Our future work includes testing real material pipeline samples and developing a data transmission system for remote operation.
The marker information is embedded in the texture mapped on the meshes. That works well for exceeding the mesh resolution to register the point cloud sets. In the current experiment, the Kinect image resolution was very low (VGA). Higher resolution of texture images enhances the registration, but integration of the depth images in volumetric space also helps texture integration.
Our next step is to design the integrated locomotive system with a high-resolution still camera for detailed image capture together with the proposed system in this paper. The proposed method is needed to automate processes for picking up the marker regions from the texture and calculating their region centroids.

ACKNOWLEDGMENTS

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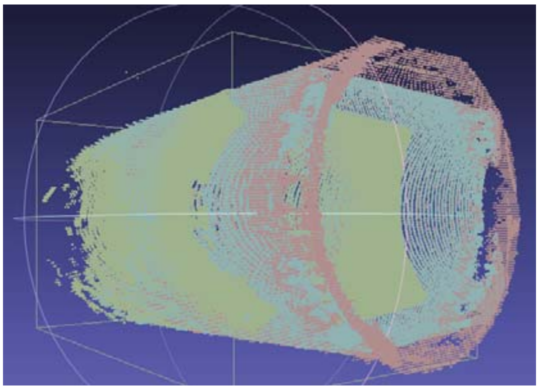

Fig. 8: Registered point cloud

3D-SCAN PLANNING OF OUTDOOR CONSTRUCTIONS BASED ON STRUCTURE FROM MOTION AND MATHEMATICAL OPTIMIZATION[1]

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ABSTRACT: *A 3D scanner or LiDAR is capable of capturing the surface shapes of objects as a set of a "point cloud" for examining, re-designing and preserving existing constructions as well as providing onsite information for building information modeling (BIM). One of the difficulties of collecting complete scans of outdoor constructions is avoiding self and mutual occlusions. Covering the entire surface of a construction usually requires scanning from multiple viewpoints. Such scanning produces hundreds of millions of 3D point data to be processed for further computations, and these multiple measurements are time and labor intensive. Therefore, it is very important to establish an effective scanning plan a priori to avoid redundancy of both labor and computational costs. In this research, we propose a method for 3D-scan planning of outdoor constructions based on photogrammetry-based modeling and mathematical optimization methods. In our proposed method, we take videos or photographs of the target site by a hand-held camera. By using the structure from motion (SfM) technique, we find corresponding characteristic points in the photographs and estimate the camera positions and orientations as well as the 3D point cloud of the target object. Next, we triangulate the corresponding points by using meshing software to obtain the rough 3D mesh model, including the target construction, other constructions, and differences in height of the ground and vegetation. Finally, we make the optimal scan plan based on the 3D mesh model by using mathematical methods. We examine the visibility and self/mutual occlusion property of each polygon of the 3D mesh and calculate the minimum number of measurement points and their layout to scan all the surfaces of the targets. Our proposed method can calculate the optimal layout of the designated number of measurement points to maximize the obtainable data.*

KEYWORDS: *Structure from Motion, 3D-Scan Planning, Photogrammetric Model, Mathematical Optimization*

❖ INTRODUCTION

A laser range scanner is a 3D surface imaging system that can obtain the surface data of target objects by scanning a number of independent ranges, and a 3D image is formed by merging these ranges. Laser scanners can be used for consistent and vast assessments of the spatial conditions required by various construction applications, such as investigation of the management of construction processes (Shih et al. 2004, 2006), monitoring as-built infrastructures (Miller et al. 2008), consequences of disasters (Watson et al. 2011), and so forth. Most of these applications require timely spatial information. Therefore, it is critical for many field applications at construction sites to collect the required information within a limited time.

One of the difficulties of collecting whole surface data of target objects is avoiding occlusions. Collecting the complete surface data usually requires measurements of the objects from multiple viewpoints. However, examining multiple surface visibilities relative to multiple viewpoints is a complicated problem. Moreover, multiple measurements are time and labor intensive, and each measurement produces a data set consisting of hundreds of millions of 3D points to be processed for further computations. Hence, it is very important to establish an effective measurement plan a priori to avoid redundancy of both labor and computational costs.

Since the advent of laser scanners, designing efficient and effective scanning methods has been developed as view planning. View planning techniques have traditionally been trial-based schemes, which segment scanned and unscanned regions in the target area to find the next best viewpoint to scan in order to minimize the number of unscanned regions. This approach includes methods for improving the efficiency of sequential scanning (Asai et al. 2007, Pitto 1999, Pulli 1999) and three-dimensional environmental map generation by autonomous mobile

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robots (Blaer and Allen 2009, Grabowski et al. 2003, Surmann et al. 2003). These view planning techniques are designed to cope with the dilemma that the geometrical topology of the object is unknown until it is scanned. Thus, the sequential scheme to estimate the next best viewpoint is based on the scanned data configuration. In essence, sequential searching approaches do not meet the demands for outdoor scanning, where estimating the minimum time and cost for the whole scanning task before starting the survey process is important for practical operation.

For this problem, the authors proposed a method for making a scanning plan by using the ground plan of a target area (Dan et al. 2010) and primitive 3D models (Dan et al. 2013) as prior information. This method uses mathematical optimization to generate an optimized initial view plan prior to the onsite survey. However, this method is based on a 2D plan or 3D primitive configurations, and hence the resultant scan plans are useful only in cases where the height differences of the objects and complicated shapes of the surrounding vegetation are not important.

In this paper, we propose an effective planning method for the 3D geometry of the job site by calculating the visibility and the amount of obtainable data based on simple photogrammetry techniques of *structure from motion* (SfM) for a preliminary survey. The view planning method itself, which follows the mathematical optimization framework, finds the least number of measurements needed to measure all the surfaces of the objects and sets up the viewpoints to maximize the total amount of scanned data within the limitation of the number of measurements.

METHODOLOGY

Overview

This paper discusses an optimization scheme with mathematical programming and a 3D version of a visibility check by using photogrammetry to obtain simple 3D modeling. Photogrammetry allows the arrangement of primitive 3D models of the target site without visiting the job site. From the set of multiple photos of the site of the target construction, the buildings can be modeled as a set of 3D primitive shape models based on the visual triangulation technique (Hartley and Zisserman 2004). The primitive models can then be used as a visibility check of the target walls from candidate viewpoints. At this point, the optimization scheme selects the minimum combination for the best scanning plan.

Mathematical Programming

Formulation

Dan et al. (2010) proposed the formulation of two 0-1 integer optimization problems for the scanning plan. We use the same formulation in this paper. The following symbols are used in the optimizations:

[Sets and Indexes]

- $i \in I$: candidate points for measurement,
- $t \in T$: triangles on the surfaces of measurement objects.

[Variables]

$$x_i := \begin{cases} 0, & \text{a candidate point } i \text{ is unadopted as a viewpoint,} \\ 1, & \text{a candidate point } i \text{ is adopted as a viewpoint.} \end{cases}$$

[Parameters]

$$a_{it} := \begin{cases} 0, & d_{it} = 0, \\ \text{the amount of scanned data on a triangle } t \text{ from a candidate point } i, & d_{it} = 1, \end{cases}$$

$$d_{it} := \begin{cases} 0, & \text{a triangle } t \text{ is unmeasurable from a candidate point } i, \\ 1, & \text{a triangle } t \text{ is measurable from a candidate point } i, \end{cases}$$

$r :=$ the upper bound of the number of measurement.

that we can calculate the values of parameters, d_{ij} and a_{ij}, from the 3D model of the target area. In this paper, we use the following two mathematical optimization models presented in (2.1) and (2.2):

$$\begin{aligned} &\text{Minimize} && \sum_{i\in I} x_i \\ &\text{subject to} && \sum_{i\in I} d_{ij} x_i \geq 1 \quad (\forall j \in J), \\ & && x_i \in \{0,1\}. \end{aligned} \tag{2.1}$$

$$\begin{aligned} &\text{Maximize} && \sum_{i\in I, j\in J} a_{ij} x_i \\ &\text{subject to} && \sum_{i\in I} d_{ij} x_i \geq 1 \quad (\forall j \in J), \\ & && \sum_{i\in I} x_i \leq r, \\ & && x_i \in \{0,1\} \quad (\forall i \in I). \end{aligned} \tag{2.2}$$

The objective function of (2.1) is to minimize the number of viewpoints. The term $d_{ij} x_i$ in the first constraint of (2.1) has the following meaning:

$$d_{ij}x_i := \begin{cases} 0, & \begin{array}{l}\text{a candidate point } i \text{ is unadopted as a viewpoint } (x_i = 0) \\ \text{or a triangle } j \text{ is unmeasurable from } i \ (d_{ij} = 0),\end{array} \\ 1, & \begin{array}{l}\text{a candidate point } i \text{ is adopted as a viewpoint } (x_i = 1) \\ \text{and a triangle } j \text{ is measurable from } i \ (d_{ij} = 1).\end{array} \end{cases}$$

Therefore, the first constraint of (2.1) means that all the triangles should be measured from at least one viewpoint. Consequently, we can find the least number of viewpoints to scan all the target triangles by solving (2.1). The term $a_{ij} x_i$ of the objective function of (2.2) has the meaning stated as follows.

$$a_{ij}x_i := \begin{cases} 0, & \begin{array}{l}\text{a candidate point } i \text{ is unadopted as a viewpoint } (x_i = 0) \\ \text{or a triangle } j \text{ is unmeasurable from } i \ (a_{ij} = 0),\end{array} \\ a_{ij}, & \begin{array}{l}\text{a candidate point } i \text{ is adopted as a viewpoint } (x_i = 1) \\ \text{and a triangle } j \text{ is measurable from } i \ (a_{ij} > 0).\end{array} \end{cases}$$

Therefore, the objective function of (2.2) is to maximize the sum of the amount of scanned data. In addition, the second constraint of (2.2) is to restrict the number of measurements to less than or equal to r. Here, r is typically equal to the optimal value of the problem (2.1), that is, the minimum number of viewpoints to scan all the surfaces of the targets. By solving (2.2), we can obtain the optimal layout of r viewpoints to collect as much scanned data for the target surfaces as possible.

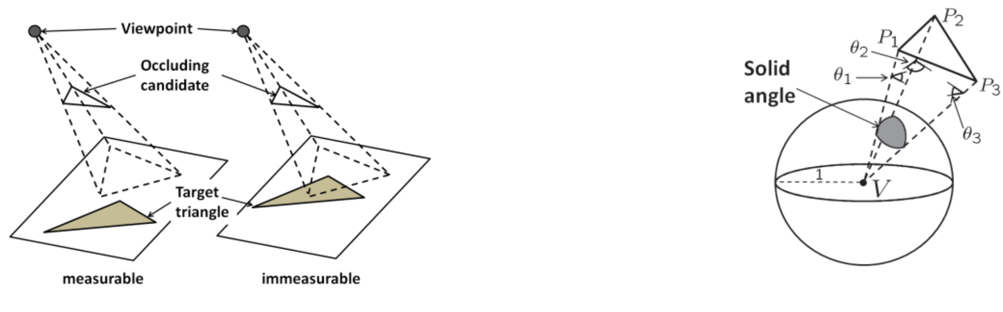

Fig. 1: Relationship between a viewpoint and a target triangle; occlusion relationship

between triangle meshes (left) and solid angle of a single triangle from a viewpoint (right)

Visibility check for optimization conditions

By using 3D shaped models, the surfaces of all objects in the target area can be approximated by triangles, some of which are the target triangles to be measured by the 3D scanner. For these triangles, we have to examine the visibility from the candidate viewpoints to make a scan plan. Moreover, the solid angles of the triangles viewed from the candidate viewpoints are needed. Figure 1 shows the relationship between a viewpoint and a target triangle. If a triangular pyramid generated by a viewpoint and a triangle intersects a target triangle, then the target cannot be scanned from the viewpoint; otherwise, it is measurable. To examine such a relationship, mathematical programming techniques are employed. The authors already proposed a method for this examination in Dan et al. (2011).

Site Modeling Based on Structure from Motion

Structure from motion (SfM) is an image-based modeling technique that recovers camera parameters, pose estimates, and sparse 3D scene geometry from image sequences [Hartley and Zisserman 2004, Brown and Lowe 2005, Snavely 2006]. First, feature points in each image are detected, and then the feature points are matched between pairs of images. Finally, an iterative, robust SfM procedure recovers the camera parameters and estimates the relative position of each camera and the 3D coordinates of the feature points.

In recent years, many SfM processes have become available as open source web services. SfM web services are capable of operating remotely and in clouds, and eventually returning 3D point cloud data that can be imported into other software. Pioneer work by Snavely (2006) showed a successful demonstration of SfM techniques applied to the real-world image sets found in Google and Flickr. The system works with an image set of photos from hundreds of different cameras, zoom levels, resolutions, times of day or seasons, illumination, weather, and amounts of occlusion. Images uploaded to Photosynth allow people to seamlessly view landmarks, public spaces and objects from all sides, as shown in Fig. 2. We focus on the combination of this remarkable simplicity of use and the great advantage of not requiring expensive camera equipment. Thus, this system has great potential for field workers conducting onsite investigations.

Photosynth also provides point cloud data that can be used for making a rough mesh by fitting primitives of planes and boxes to represent the surface of the ground and buildings by tracing the 3D point cloud shape. Simple meshing techniques can also be used for meshing natural objects such as trees and shrubs. Based on the mathematical model presented in the previous section, candidate points of the scan positions, target object surfaces and surfaces of other objects are assigned to the mesh model. A 3D geometrical copy of the target site is created to check the visibility of the target building so that the optimal viewpoint set for scanning the target object can be computed by the mathematical programming described in the previous section.

Fig. 2: Web service for SfM by Microsoft Photosynth

System Configuration

Figure 3 shows the configuration of the schematic system for optimization of the scanning plan developed by our group [Inui 2013]. This system is designed not only for desktop users but also for field workers. The key design approach is introducing the HTML5 standard for compatible implementation of both the graphical view capability on the client side and a standard messaging interface for interactive communications. WebGL is an implementation of the JavaScript version of the OpenGL ES (embedded system) package that follows the HTML5 standard. HTLM5 resources are basically web pages running on web browsers, but they are also capable of handling local graphics hardware resources for sophisticated 3D representation. On the server side, the core functionality for computing an optimal scanning plan is realized by the native C++ solver library of CPLEX, which can be wrapped by Java Native Access (JNA) to allow access by Java codes. Thus, a consistent system implementation with Java provides a Java Servlet interface to communicate with the client side. The client devices could be lightweight tablet PCs, which can be used at the job site and can easily match the physical

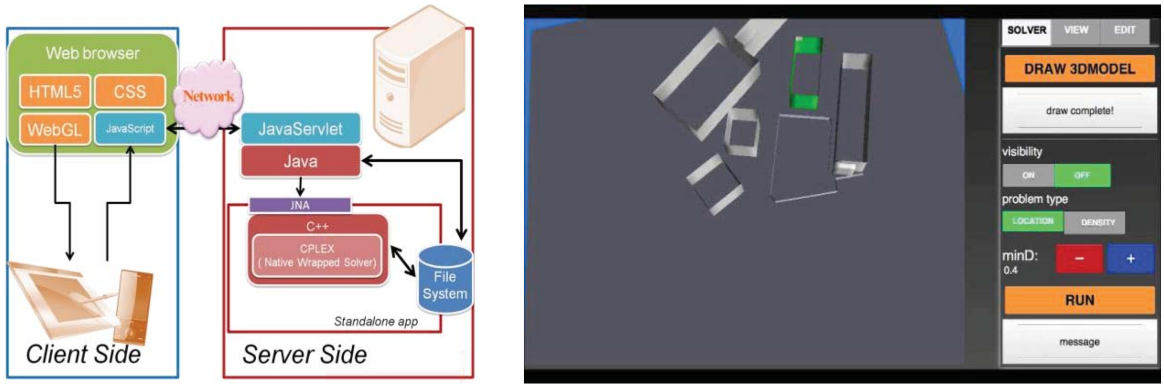

Fig. 3: Web application implementation for scanning plan [Inui 2013]

conditions immediately before laser scanning with the derived scanning plan. We used this system as a platform to derive an optimized scanning plan by assembling the 3D geometry information based on a visual survey with SfM.

EXPERIMENT

Video Survey and Site Modeling

The target location is a two-story building on the campus of Kansai University, Japan. As shown in Fig. 4 (left), the target building is surrounded by trees on a small rise of land and next to a public square. Walking around the target site, we shot a video with a hand-held small digital camera to capture the scenery of the target site. Six to 7 minutes of footage was split into thousands of image frames, from which 770 images were selected so that the image set contained several smooth sequences captured in the continuous video. We applied the SfM process to this image set. The image sequences were used to produce a "track" in the SfM for a continuous navigation view on the Photosynth viewer (Fig. 4 (left)). A 3D point cloud was acquired as well (Fig. 4 (right)).

Fig. 4: Image frame for onsite survey (left) and generated point cloud by SfM (right)

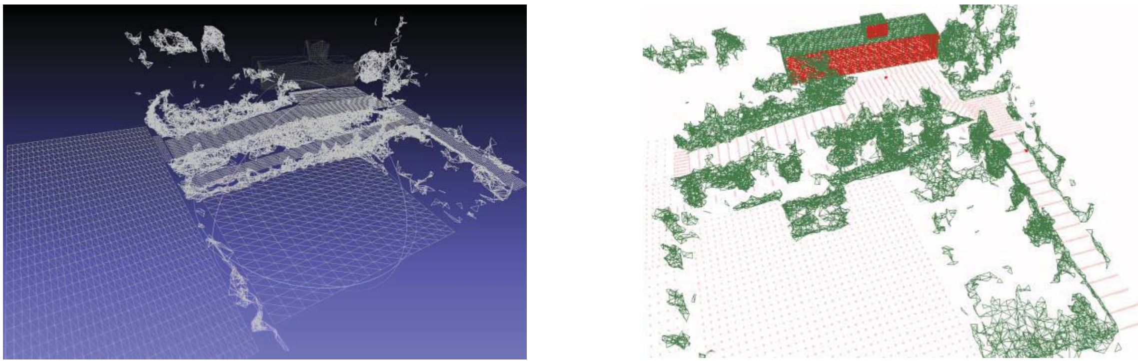

Figure 5. Mesh models of the target site (left) and derived optimal scanning plan (right)

Scanning Plan

Mesh models from the point cloud were prepared for the whole site, as shown in Fig. 5 (left). We modeled the structure of the buildings with the CG modeling and rendering software, Blender, to which the actual scanned point cloud could be imported and overlaid. Then we traced the point cloud to arrange the polygons to be aligned in physical dimensions. Rather than modeling the detailed shapes of the buildings, we set cuboids circumscribing the point cloud to represent the corresponding buildings. Although this process requires manual work, simple polygon models with precise location relations of the buildings could be reconstructed. The point cloud data has overwhelming numbers of unorganized 3D dots collected from photos with many viewpoints, and yet form incomplete outlines of the scene due to the passive manner of the visual triangulation measurements. Therefore, an off-the-shelf meshing technique cannot be applied. Ground geometry, including slopes and height differences can be modeled in the same way. Since we want to add the rough shapes of the volumes of trees and bushes that might occlude the target building from certain viewpoints, a simple meshing scheme such as the ball-pivoting method [Bernardini 1999] can be applied to create meshes of the vegetation from the point cloud.

We chose the north-facing walls of the two-story building as the scanning target. The target surface meshes are represented with red lines (3.6k vertices, 3.8k faces) as depicted in Fig. 5 (right). Green lines show other walls, constructions and vegetation (8.6k vertices, 16.8k faces in total). The target walls are surrounded by tall trees, whose close positions are preferable for scanning the first-floor wall. Since the second-floor construction is set back from the wall of the first floor, more distant scanner positions could be suitable. Many paths and a flat square appear at different levels in front of the target wall. The visibility of the target walls from each ground position is not simply acquired. Small red dots in the figure are the candidate positions (3.9k) for locating the scanner, out of which only two dots are selected. These two thick red dots are the optimal positions for the resultant plan. The computational time to solve the mathematical programming was 2 hours.

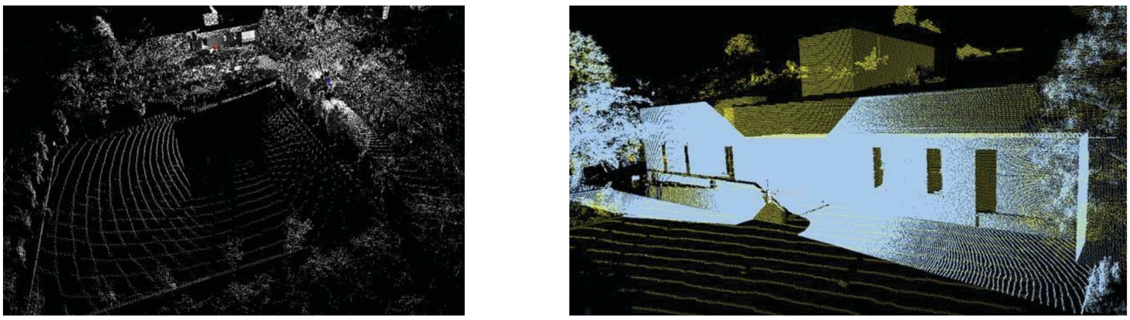

Figure 6. Point cloud by laser scanning; whole view (left) and close view of the target (right)

Evaluation of the Plan

We also conducted actual laser scanning by using the 3D scanner (LMS-Z420i, Riegl) according to the derived

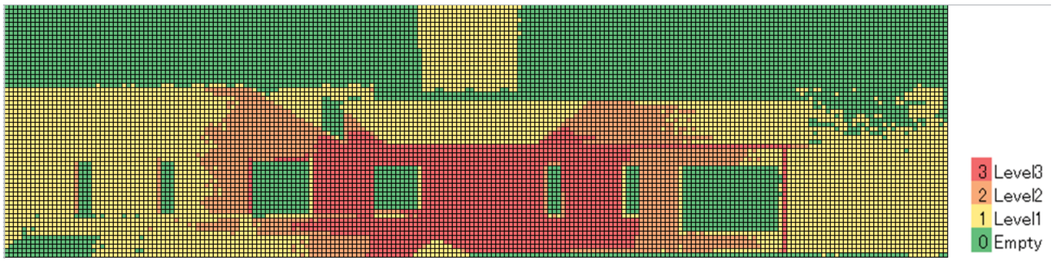

Figure 7. Scanning result based on the scan plan; colored with LOD (level of details) by the GSA guideline

scanning plan. In Fig. 6 (left), white dots show the overall point cloud data acquired by the laser scanner. Fig. 6 (right) shows a close shot of the point cloud of the target surfaces. The white dots are captured from the closer scanner position and the yellow dots are from the other scanner position.

According to GSA BIM Guide Series 03 (3D Laser Scanning, USA General Service Administration), the general quality levels of the scanned 3D point data are described based on point density or resolution of the point cloud, because the level of detail or resolution of the data has a trade-off relative to the distance between the target and the scanner. Table 1 lists the "Project Definition Matrix", which can be used to identify how the 3D imaging data will support the project objectives. According to this matrix, the resultant scan data can be categorized as shown in Fig. 7, which schematically depicts the data density of the acquired point cloud data.

The green color in Fig. 7 shows incorrectly scanned areas that contain no point data. The green regions inside of the wall are window panes, which may reflect the scanning laser and are not measured by this device. Every other solid surface on the wall is covered with scans of at least level 1 quality.

CONCLUSION

This paper showed that a simple survey recorded with a hand-held digital (video) camera can be used for effective laser scanning. Although the target setup was quite simple, an onsite situation including vegetation and ground level differences can be taken into account for a visibility check to increase the reliability of the scan plan.

At this point, our implementation requires manual work for preparing mesh models from the point cloud before applying the mathematical programming scheme. Developing an easy-to-use, fully-/semi-automatic modeling system is our next step. Also, it is within our focus to let the user select the target levels of detail of the resultant laser scanning quality into the optimization problems.

Table 1: Level of details and the point cloud resolution (excerpt from GSA BIM Guide Series)

Level of Detail	Category	Resolution mm x mm (in x in)
Level 1	Point cloud	152 x 152 (6 x 6)
Level 2	Plan Elevation Surface model Point cloud	25 x 25 (1 x 1)
	Elevation Surface model Point cloud	25 x 25 (1 x 1)
	Elevation Point cloud	13 x 13 (½ x ½)
Level 3	Plan Elevation Point cloud	13 x 13 (½ x ½)
	Elevation Point cloud	13 x 13 (½ x ½)
Level 4	Surface model Point cloud	13 x 13 (½ x ½)

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THE ROLE OF CENTRAL COURTYARD AS A PASSIVE STRATEGY IN ISLAMIC ARCHITECTURE[1]

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ABSTRACT: *In Islamic architecture, the courtyard is considered a significant element of the design whether it is residential, commercial, educational, or even religious. Historically, the climatic requirements were the driving forces behind the courtyard development specifically in hot-dry and hot-humid condition. Furthermore, the inclusion of a courtyard in a building provides a private, secure space for family daily activities. Moreover, it improves the thermal performance of buildings as it provides plenty of natural daylight and ventilation for the main living areas.*
The primary aim of this analysis is to investigate the courtyard's contribution to building thermal comfort specifically in terms of thermal performance, natural ventilation, and natural daylighting. Then, the results of the simulation are evaluated and compared to the energy performance of a conventional building with the same geometries which is considered benchmark to the results of altered simulation setups and conditions. The analysis also aims to offer some strategies concerning courtyard buildings in order to provide optimum designs for natural ventilation and thermal comfort.
In the analysis, DesignBuilder software is used as a simulation tool for the energy performance of buildings calculations and to evaluate the influence of the inclusion of courtyard on the energy consumption, daylight, and natural ventilation behavior of the buildings. In general, the final results show a reduction in the year-round total energy consumption and better performances of natural ventilation and daylighting for courtyard buildings when compared to a similar conventional form of buildings performances.

❖ INTRODUCTION

Courtyards in buildings are old architecture elements that exist in different forms and shapes in many parts of the world across various climates and cultures (Aldawoud, 2007). Some of the oldest courtyard houses are found in the oldest civilizations of Iran as well as China, and dates back to 5000-3000 BC (Edwards et al., 2006). There are many reasons for the inclusion of courtyards into houses and buildings including privacy, cooking, gathering, and provide a good space during hot summer seasons. However, the courtyards are common in regions with hot-dry and hot-humid climates, as in the Middle East and the tropical regions. The open courtyard is usually the center of the building which creates private space and brings daylight, fresh air (ventilation) which provides some cooling effects for the house (Aldawoud & Clark, 2007).
Islamic civilization absorbed various influences of all different cultures with an integration of its culture and values in all aspects of life. On the architectural level, Muslims rely on and absorb the skills and experiences of the cultures of the newly conquered lands. The development of the structures and furnishings such as arches, vaults, domes, minarets, and arcade courtyards were adapted from the Byzantines and Persians civilizations and became symbolic of Islamic architecture. The internal as well as the external architecture of buildings were decorated in splendid geometric patterns with complete harmony of color and scale.
In the local Islamic architecture of the Mediterranean and the Arabian Gulf regions, the existence of central courtyard was evident in large, public scale and in private buildings as well. The public plaza which is a form of a large courtyard was the central city space where the public could meet and interact. On the other hand, in almost each building the private central courtyard provides air, light, privacy, and security to all adjacent rooms (Fig. 1). The courtyard in Islamic architecture serves many dimensions including cultural, environmental, structural and,

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above all, religious one. Privacy is a special need in a Muslims housing. The courtyard provides a proper design to create a physical separation between spaces of males and females (inner and outer spaces). However, the environmental function of the courtyard is significant as it provides natural light for all spaces surrounding it. Furthermore, natural ventilation during hot seasons occurs through the courtyard especially in hot climates. During daytime the air in the courtyard becomes warmer and rises. This draws out the internal warm air into the courtyard through the openings. Consequently, it makes an air movement inside the adjacent spaces.

Figure 1. Public and private courtyard (adapted from Edwards, 2006)

In the Arabian Gulf region where most of the region is a desert with a low and unreliable rainfall, the courtyard was developed over a long period of time to create a solution to the severe hot climate. The temperature during the summer is high, reaching well over 45°C in most parts. Courtyards in houses played a significant role as an important aid to cool buildings in this unfavorable environment extreme climatic condition (Fathy, 1972).

The courtyard is a passive cooling strategy and a mediator zone between its adjacent spaces and the exterior environment maximizing both natural ventilation and daylight (Samadi, 2014). However, the level of thermal performance and the comfort conditions in a courtyard building is determined by the microclimate and the ambient conditions forces acting on it, particularly the air velocity (Brown, 19853). Furthermore, this type of buildings' thermal and environmental performance varies depending on many other parameters such as courtyard sizes and dimensions, courtyard orientation, shading, and the treatment of the building exposure and the construction materials used in building exterior surfaces.

Previous research work investigated through field studies and computer simulation the thermal performance of courtyard buildings in different climatic regions, nevertheless, much more remains to be done. Addressing the needs for new effective passive design strategies has become one of the main issues that architects and engineers should employ in their designs to reduce buildings consumption of energy. In this study, one of the main focuses is to investigate the thermal performance and comfort conditions of courtyard buildings compared with conventional buildings and the potential benefits of using such passive and low energy strategy to improve indoor environments.

MODELING APPROACH

For the purpose of the investigation, computer models representing different conditions for typical courtyard and conventional buildings are created in DesignBuilder software. All constructed models represent realistic low rise office buildings characteristics and construction practices [Fig. 2]. Weather data and the hourly scheduling requirements including occupancy and lighting are considered in the simulation process. All computer simulations are undertaken without heating or cooling systems running.

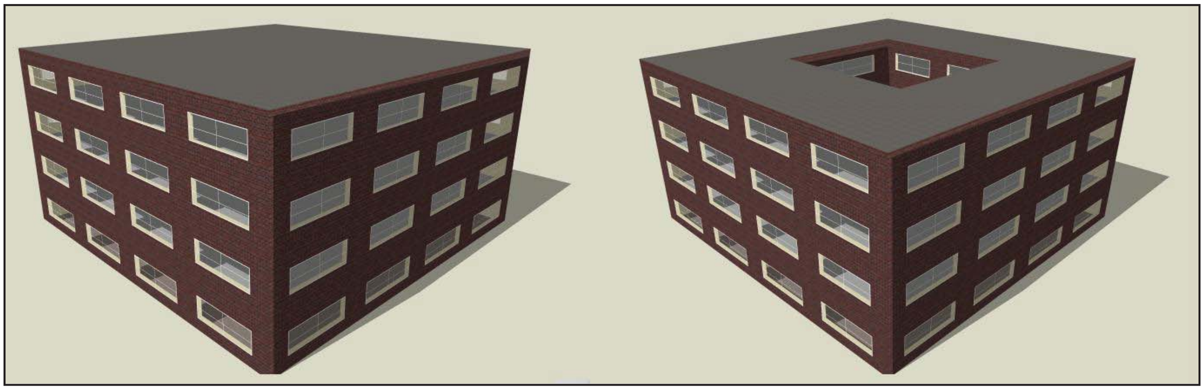

Figure 2. Typical courtyard and conventional buildings

Both main building alternatives are four stories height with a total area for the courtyard building of 1892.08m^2 excluding the courtyard area. The building includes a central courtyard with an area of 492.41 m^2. All building walls including the courtyard walls have external windows. The conventional building area is 2384.49m^2 with windows on the façade in all directions. The geometric measurements and characteristics of all investigated alternatives including all three dimensions of length, width, height, and construction materials are constant throughout the simulation process. Windows types and window-wall ratio are the main variables in the simulation. Table 1 summarizes the conditions of both types of buildings. The external envelopes of both buildings are considered to be airtight with excellent construction conditions. A detailed weather data for Dubai, in the United Arab Emirates is used which is a good representation for the hot, humid climate. Simulations have been run for the whole year for different conditions. Summer season in Dubai lasts from 1st of April to 30th of September while winter season lasts from 1st of October to 31st of March. The winter outside design dry bulb temperature is 12.9°C whereas the yearly max design dry bulb temperature is 42.9°C and coincident wet-bulb temperature is 23.6°C. Northerly prevailing wind direction of 0° is considered the dominant wind with the highest speed.

Table 1. Floor area for both courtyard and conventional buildings

	Courtyard Building Area [m^2]	Conventional Building Area [m^2]
Total Building Area	1892.08	2384.49
Net Conditioned Building Area	0.00	0.00
Unconditioned Building Area	1892.08	2384.49

The main variables in the study are:

- Windows types: different types of glazing are used in the study.
- Window-wall ratio: different ratios of are investigated.
- Ventilation rate: this investigation used CFD method to calculate different conditions of wind driven natural ventilation for both types of buildings.
- Natural daylight: the natural daylight illumination levels are investigated for both types of buildings.

ANALYSIS OBSERVATIONS AND FINDINGS

In general, results of values gathered over 8760.00 hours show that the two building types and their alternatives thermal performance, natural daylight and ventilation rate differ based on the configuration of measures or the variables. The type of glazing and the glazing wall ratio had a significant impact on the thermal performance of the two building types. Next is a description for the results and observations of various aspects of thermal performance, daylight, and ventilation of different conditions. Operative temperature is used as a measure of thermal comfort condition inside the spaces within the building.

The effects of glazing type and window-wall area ratio:

Due to the intense solar radiation in hot-humid climate, a large heating gain occurs through windows which in turn increase the cooling load and overall energy consumption. The results show that, in general, the central courtyard building exhibits a better energy performance than conventional building. Based on ASHRAE 55-2004 standards, the time with not comfortable conditions within the courtyard building is 2836.00 hours while it is 2969.00 hours for the conventional building. Table 2 shows that the courtyard building in hot humid climate can save up to 21% of energy consumption compared to conventional building with the same geometric proportions.

Table 2. Thermal comparison between courtyard and conventional buildings

Building Type	**Percentage of saving in Energy Consumption**
Conventional	
Courtyard	-21%

In comparison among glazing types used for the courtyard building, the thermal performance of the single clear glass was the worst compared to all glazing types due to high heating gain [Figure 3]. The results also show significant energy efficiency for incorporating the courtyard compared with the conventional building. Energy savings was higher when using low U-value glazing types and lower glazing percentages for the courtyard walls. Table 3 summarizes the estimated percentage of total energy savings in the courtyard building for different glazing types at based on the thermal performance of single glazing when windows are60% of the wall area. Double clear glass performs better than single clear glass because it reduces the solar heat gain. It saves 21% of the total energy consumption. Low-e glass performs better than double clear glass and it reduces the heat exchange and saves 26% of the total energy

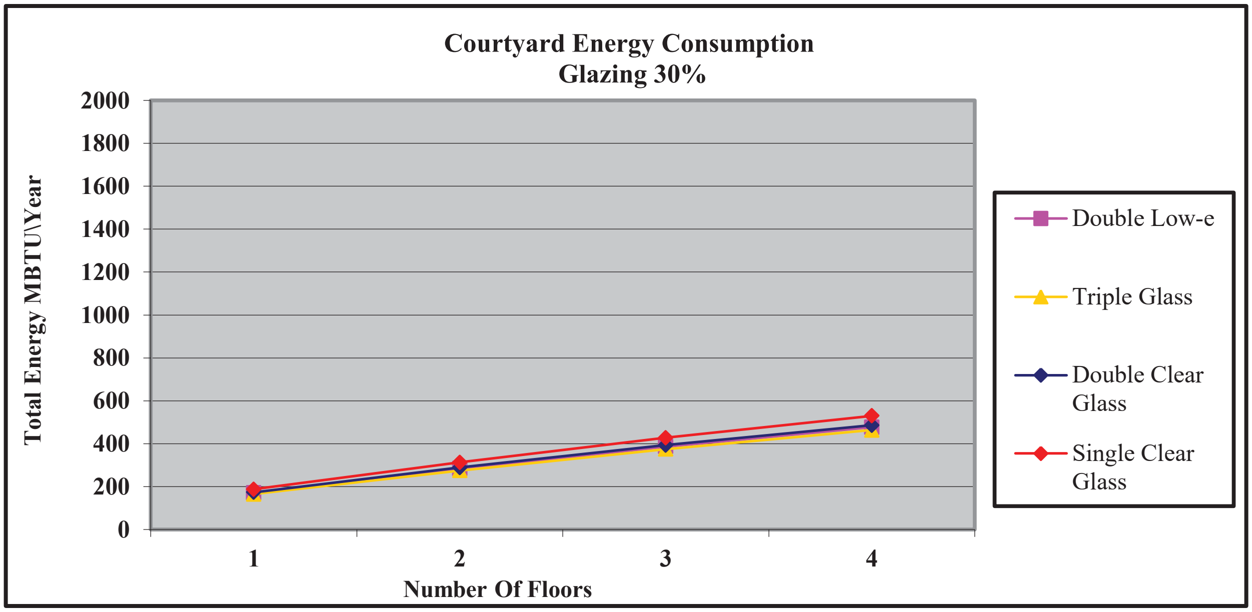

Figure 3. Courtyard building glazing thermal performance

consumption. Triple glazing performs the best in hot-humid climate. It reduces the total energy consumption by 29%.

Table 3. Glazing Thermal Performance Compared with the Single Clear Glass Thermal Performance (60% window-wall ratio)

Glazing Type	**Percentage of saving in Energy Consumption**
Single Clear Glass	
Double Clear Glass	-21%
Double Low-e	-26%
Triple Glass	-29%

Changing the window-wall ratio to 30% glazing improves the thermal performance of the courtyard building as the total energy consumption of this configuration reduces because of less exterior solar heat gain. The thermal performance of single glazing still the worst among all other investigated glazing types. As shown in Table 4, the courtyard with double clear glass energy consumption was less by 9% compared with a courtyard with single clear glass. A courtyard with double low-e glass energy consumption was 10% lower compared with a courtyard with single clear glass. Also a courtyard with triple clear glass annual energy consumption is less by 12% than a courtyard with single clear glass total energy consumption under the same conditions.

Table 4. Glazing Thermal Performance Compared with the Single Clear Glass Thermal Performance (30% window-wall ratio)

Glazing Type	**Percentage of saving in Energy Consumption**
Single Clear Glass	
Double Clear Glass	-9%
Double Low-e	-10%
Triple Glass	-12%

The influence of the courtyard on natural ventilation:

The results show that higher ventilation rates in courtyard building lower the indoor temperature in adjacent spaces of the courtyard and consequently the operative temperature compared to conventional building. The cross ventilation rate through the windows is found to be dependent on the wind direction and climatic conditions in both types of buildings. Wind blowing over and around a building develops strong pressure gradients between the windward (the side facing the direction of the prevailing wind) and leeward sides of the building as shown in Figure 4 and Figure 5. High pressures occur on the windward side of the building as the wind hits the exterior walls, slows down, and creates a positive pressure. Then the air flow separates from the building at the corners which creates a low negative pressure or suction. Low pressures also occur on the leeward side as the air builds up on back face of the building which creates a negative pressure. It is also found that the central courtyard in building creates a negative pressure zone within the courtyard which improves the natural ventilation performance [Fig. 6].

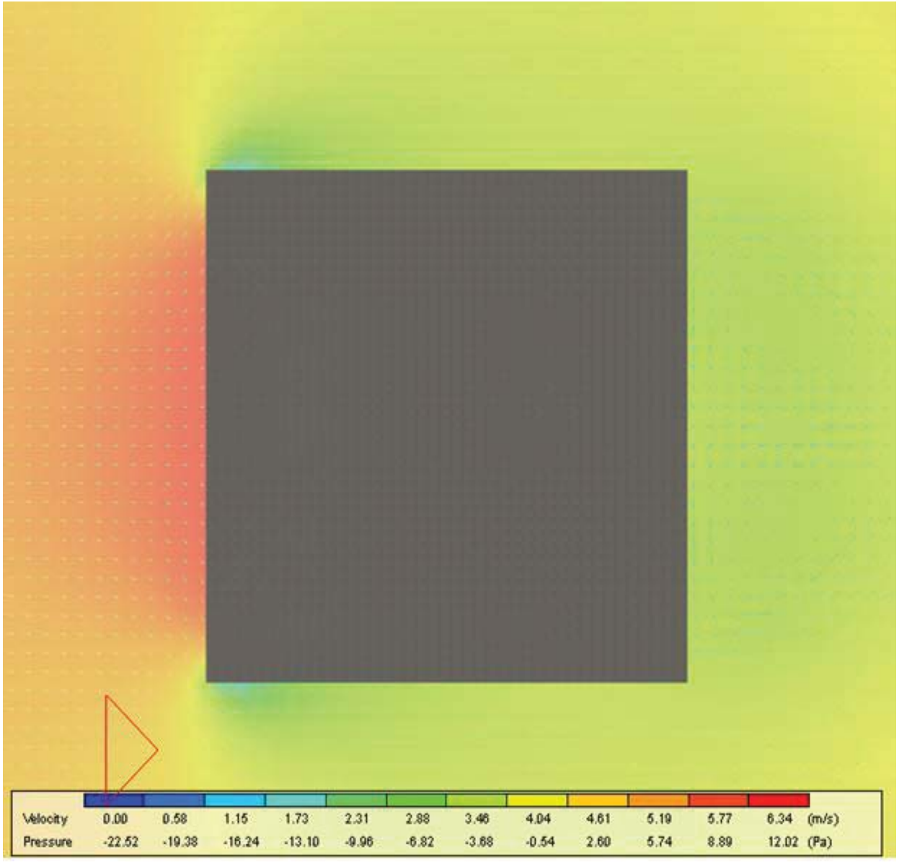

Figure 4. Wind pressure and velocity around the conventional building

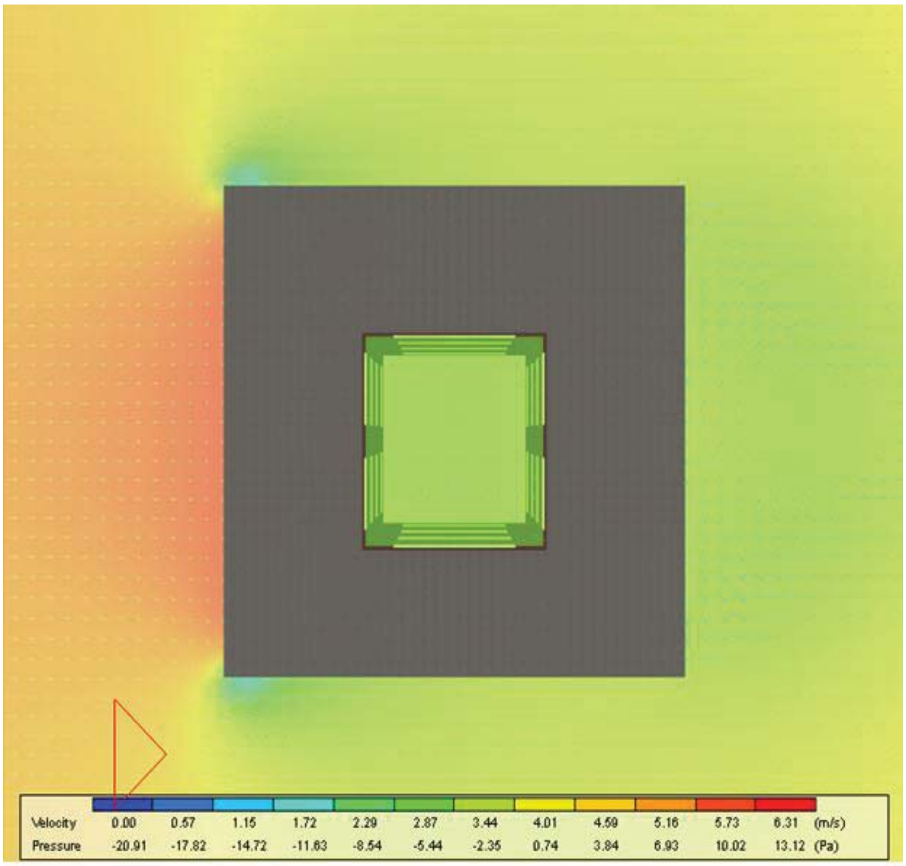

Figure 5. Wind pressure and velocity around the courtyard building

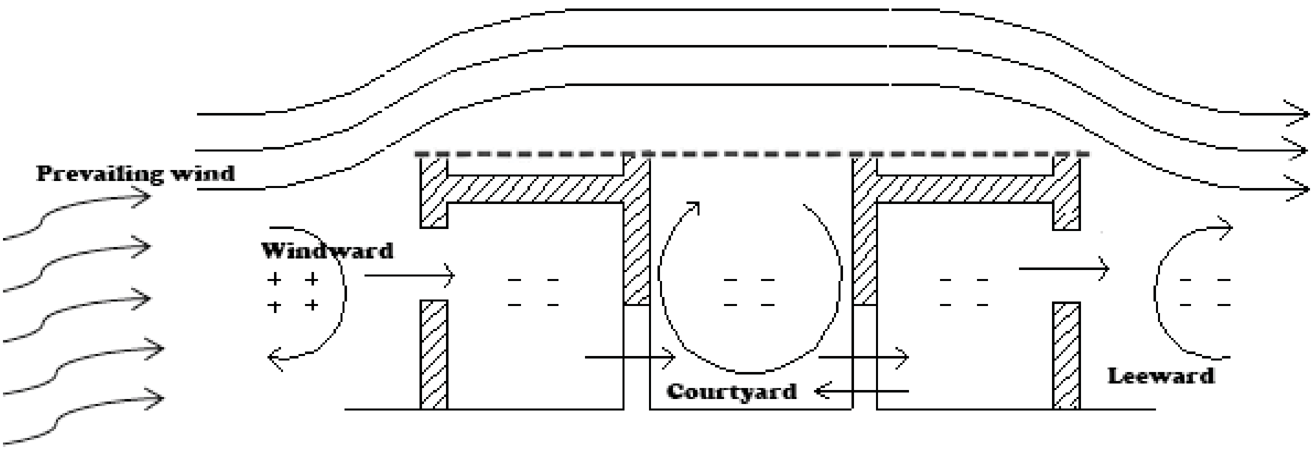

Figure 6. Pressure distribution around the courtyard building

The annual temperature distribution for both building types tends to be higher than comfort temperature most the year due to extreme weather conditions and high solar heat gain. Figure 7 shows that the operative temperature of 32°C occurs 1,926 hours per year in the courtyard building. The temperature tends to be a little cooler in spaces during winter as the operative temperature of 32°C occurs 1,200 hours per the season. The operative temperature of 27°C occurs 584 hours per year in the building. This is an improvement of 36% compared with the conventional building type.

On the other hand, the conventional building shows poor internal ventilation performance throughout the year. The interior operative temperature at 27°C or below occurs 374 hours. The operative temperature of 32°C occurs 2,079 hours per year as shown in Figure 8.

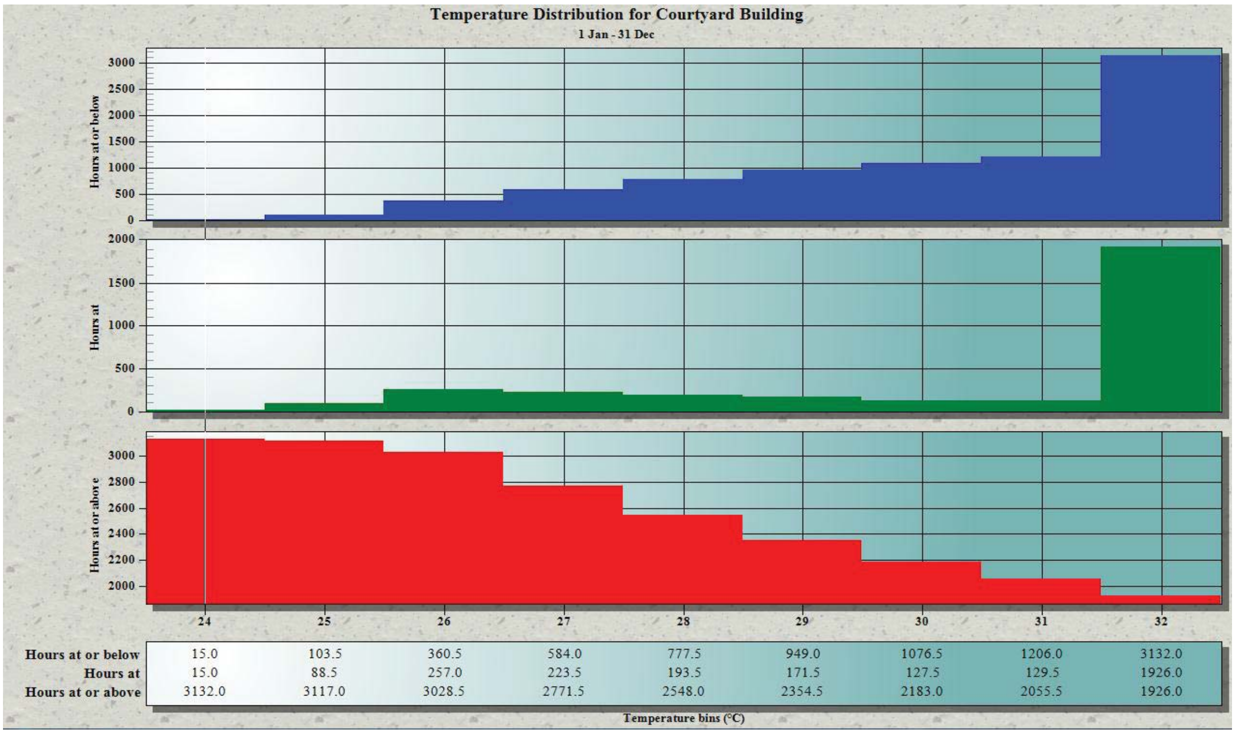

Fig 7. Courtyard building interior temperature distribution

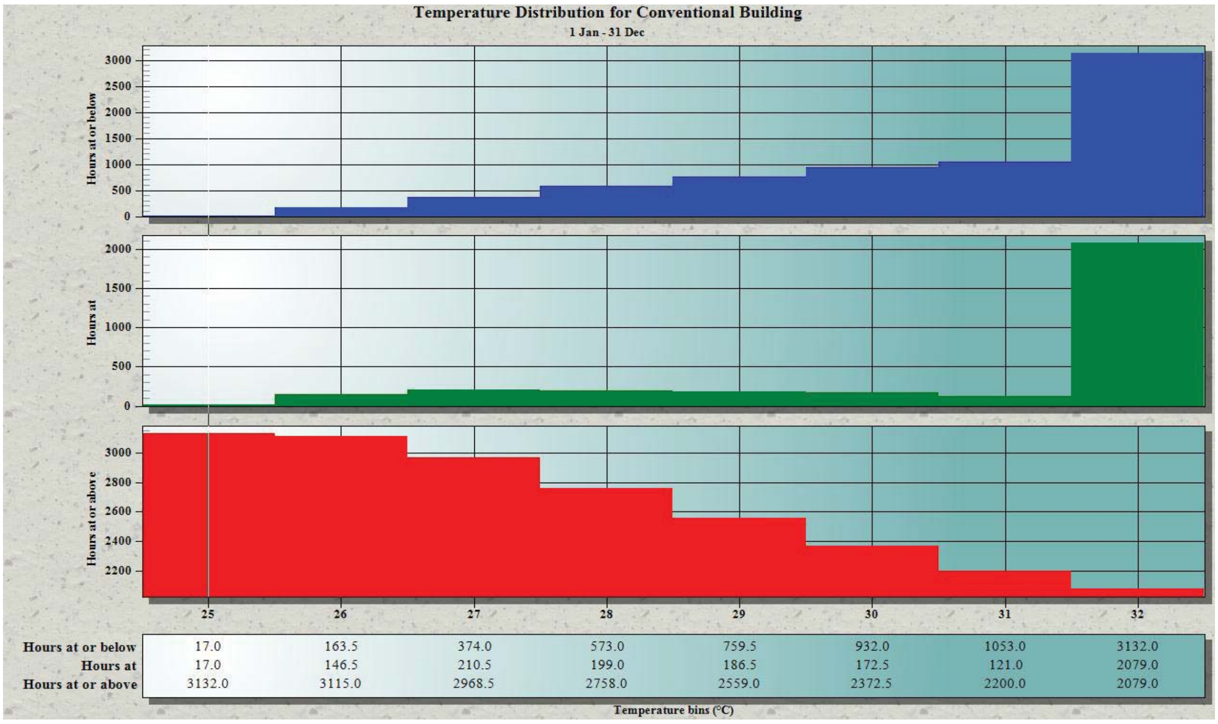

Fig 8. Conventional building interior temperature distribution

The influence of the courtyard on daylighting distribution:

In addition to the direct connection to the outdoor environment, it is found that the courtyard is effective in improving the light level for the building adjoining parameter zones up 3-5 meter depth depending on the glazing type and the glazing-wall ratios (window size) which consequently increases the visual comfort in the indoor environment and reduces the building energy consumption effectively. Figure 9 illustrates the effect of the courtyard on the daylight distribution in building’s interior zones. The illumination levels in courtyard adjacent spaces are very strong compared with interior zones. The light level could reach 2000 Lux close to the windows which exceeds the recommended light level of about 300-500 Lux. The illuminance level for internal spaces away from windows is satisfactory compared with the conventional building daylight distribution performance for the internal spaces. Figure 10 shows the indoor illuminance level for the internal zones of the conventional building. It increases gradually around the windows area to reach a maximum level of 2200 lux. The level of daylighting illumination diminishes as it goes deeper into the interior spaces to reach the lowest value of 8 Lux and a very low daylight factor in some parts of the building. The lack of an access towards the exterior windows area leaves most of the interior spaces below the recommended light level.

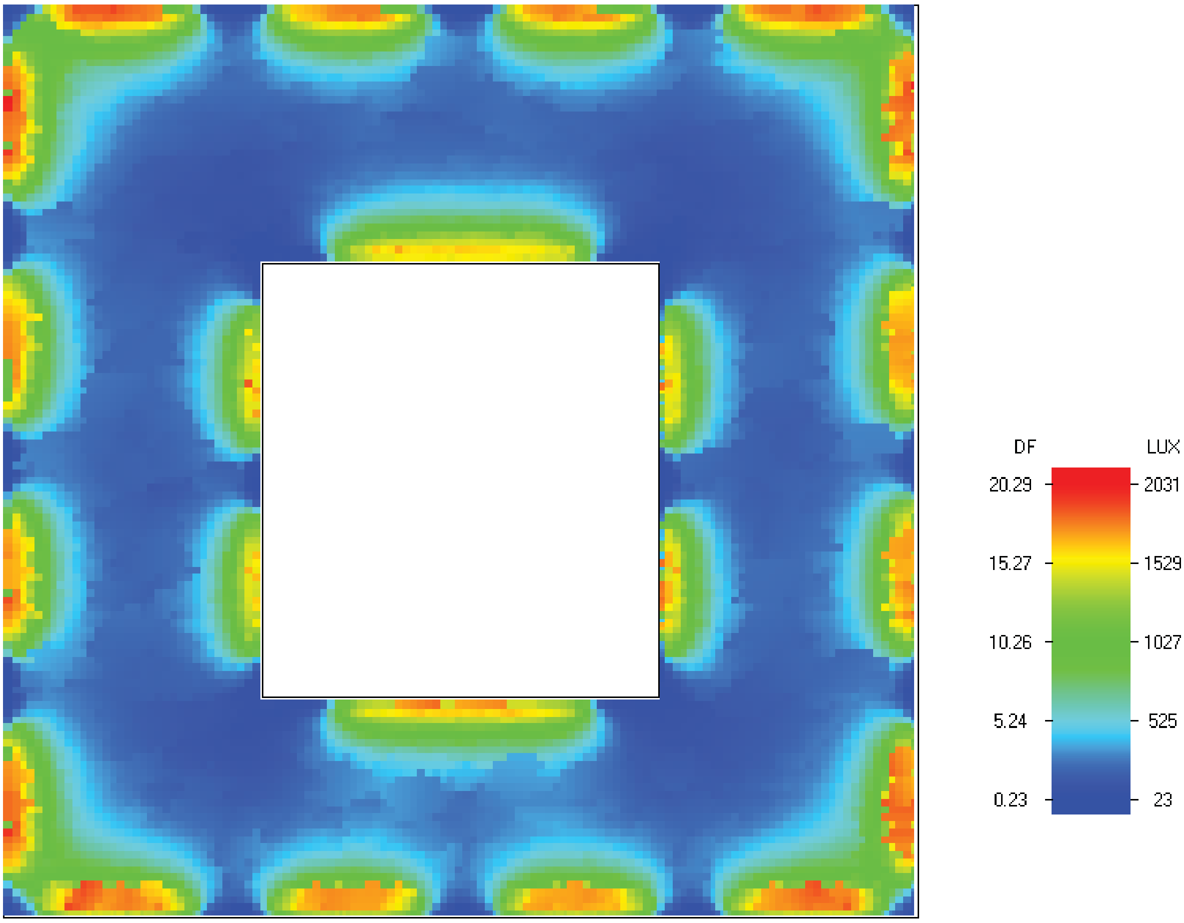

Fig 9. Courtyard daylight distribution performance

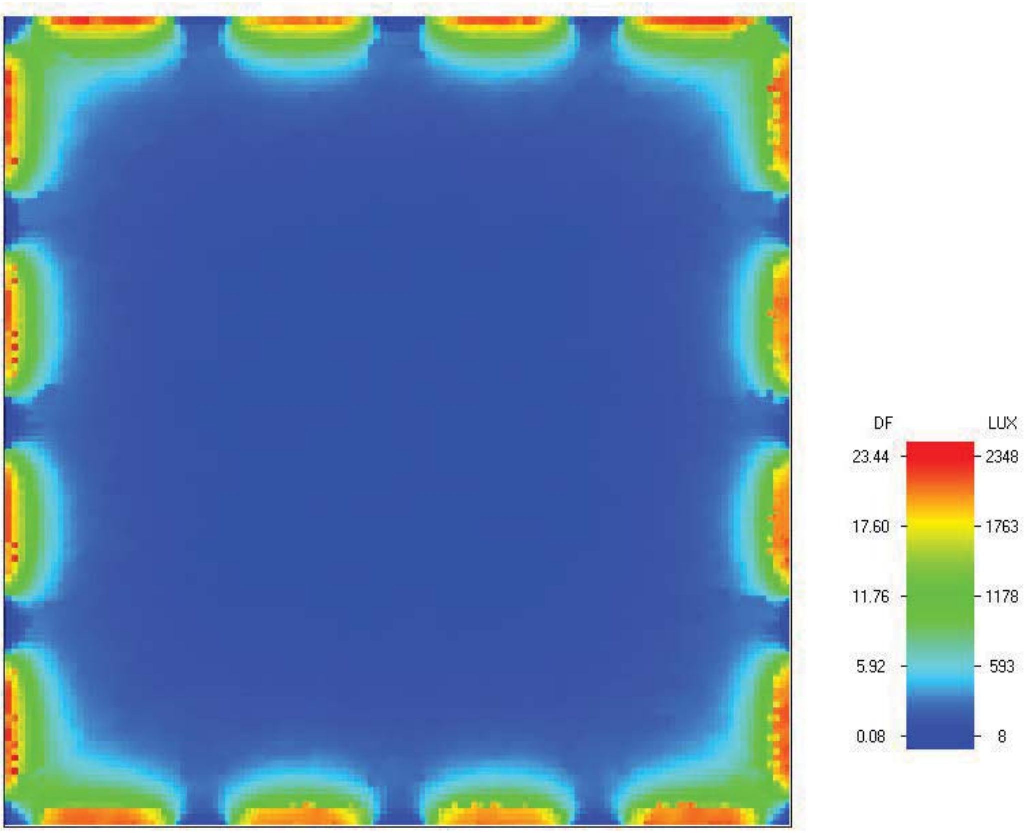

Fig 10. Conventional building daylight distribution performance

CONCLUSION

From the results obtained in this study, it can be seen that inclusion of central courtyards has the potential to improve the thermal performance and energy consumption of buildings. It has also significant effects on ventilation rate and daylight distribution performance within the building and thus the thermal comfort level. It can be also concluded that glazing types and window-wall ratio (size) affect the annual cooling, heating, total annual consumption of the two types of buildings based on the selected variables. Comparing the two building types with same characteristics and based on the total annual consumption demonstrated that the courtyard building is a better option in hot humid climate. Despite the severity of the climate, the indoor air temperature for the adjacent spaces of the courtyard is lower than the outside ambient temperature level because of stacking the wind forces to generate airflow within the courtyard and vent the warm air out. It is found that the comfort standards recommended by ASHRAE are hard to be achieved under extreme conditions of hot humid climate.

In all of the alternatives investigated within the scope of the present study, the courtyard building shows better performance in interior natural ventilation than the conventional building. The courtyard accelerates natural ventilation and airflow and evacuates the heat upward. However, the combined effects of the speed and the direction of the air flow and window size have significant effects on the ventilation air flow rate within the building and thus the thermal comfort level. The findings show that maximum cross ventilation rate occurs with larger window-wall ratios (openings sizes) which help to cool the adjacent parameter spaces faster through the courtyard.

The central courtyard buildings offer abundant of natural daylight compared to conventional buildings. However, the light distribution level for the adjacent spaces of the courtyard exceeds the recommended lighting comfort level especially around exterior windows, but daylight can significantly reduce the need for artificial lighting. Integration of natural daylighting strategies with electrical controls can provide automatic adjustments to provide minimum light levels with minimum electricity use.

Further research and more experimental investigation for courtyard buildings performance are encouraged. The same methodology utilized in this research could be followed to explore the impact of different courtyard geometries and proportions on the thermal performance and comfort standards. Further studies may also discuss major climatic factors such as the impact of orientation and examine the influence of rotating the courtyard buildings and to find out the optimum orientation angle which contributes for high energy savings.

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BIM-BASED ENVIRONMENTAL ASSESSMENT IN THE BUILDING DESIGN PROCESS[1]

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ABSTRACT: *Today, climate change is an issue of great concern. In addition, the building sector is considered to be one of the major energy users causing considerable amount of greenhouse gas emissions. Although, energy-efficient buildings are built today that use low amount of energy during operation, the embedded energy from construction and production of building material can still be relatively high. This paper focuses on the application of Building Information Modeling (BIM) using Environmental Product Declaration (EPD) to assess the environmental impacts from building materials and production to enable the designers to make environmentally friendlier decisions. Toward this approach, we propose a model which is examined in a case study of a roof structure on a commercial building which was constructed by off-site prefabricated roof-elements. As a result, the feasibility of the proposed model is appreciated in the assessment of the carbon footprint and embodied energy of the building materials and components. The proposed model needs to be further developed regarding the specification of the materials and components to make the information exchange between the BIM model and EPD in the environmental assessment of the building design more practicable.*

KEYWORDS: *Building information modeling, Environmental product declaration, Life cycle energy, LCE, Embodied energy, Environmental impact, Carbon footprint*

❖ INTRODUCTION

Global warming is an issue of great concern. In addition, the building sector is considered to be one of the major users of energy causing considerable amount of greenhouse gas (GHG) emissions. According to a report by the European commission (2009), buildings account for approximately 40% of the European Union's total energy use and GHG emissions. In Sweden, the building sector is estimated to contribute to 28% of the total energy use and consequently 20% of GHG emissions (Toller et al. 2009).

Efforts in mitigation of the environmental impact of buildings are focused on reduction of the operational energy use, including heating, cooling and domestic hot water supply. Although new solutions have been proposed in the optimization of the buildings' operational energy use in the recent decades, researchers have found that energy usage in construction and production of material is still relatively high. Yung et al. (2013) argue that the production of materials can contribute to a substantial percentage of the total energy use in a building's life. Traditionally, buildings were constructed from local materials with low energy use and low environmental impacts but in new buildings, materials supplied on a global level such as cement, aluminum, concrete and PVC are used that increase the energy use and environmental impact (Zabalza Bribián et al. 2009). Dimoudi and Tompa (2008) express that the GHG emissions associated with the construction and consequently, material production, are gaining greater importance when buildings are becoming more energy-efficient. Hence, the reduction of the environmental footprint of the building requires a general view of the whole building's life rather than restricting it to operational use only.

This research disregards the building's operation and concentrates on the environmental footprint caused by production of material and components. The main purpose of this research is to investigate the employment of Building Information Modeling (BIM) in the sustainable material selection, i.e. materials with low energy content and low environmental impacts, to facilitate decision-making for architects and designers in the building design process.

THEORY

Life Cycle Assessment (LCA)

The prominent technique used in sustainability assessment of buildings since 1990 is Life Cycle Assessment

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(LCA), also known as cradle to grave analysis (Fava 2006). LCA is applied in the building's global and regional impact assessment. The impact categories are extensive e.g. global warming potential, proportion of ozone layer depletion, eutrophication, and acidification which are evaluated based on energy consumption, waste generation, etc. (Ramesh et al. 2010). The procedures of LCA are illustrated extensively in the ISO 14040 (2006) and ISO 14044 (2006) standards. Four different stages are studied in the LCA of a building; production, construction, operation and demolition (Erlandsson & Borg 2003; Zabalza Bribián et al. 2009). Figure 1 illustrates these stages more in detail.

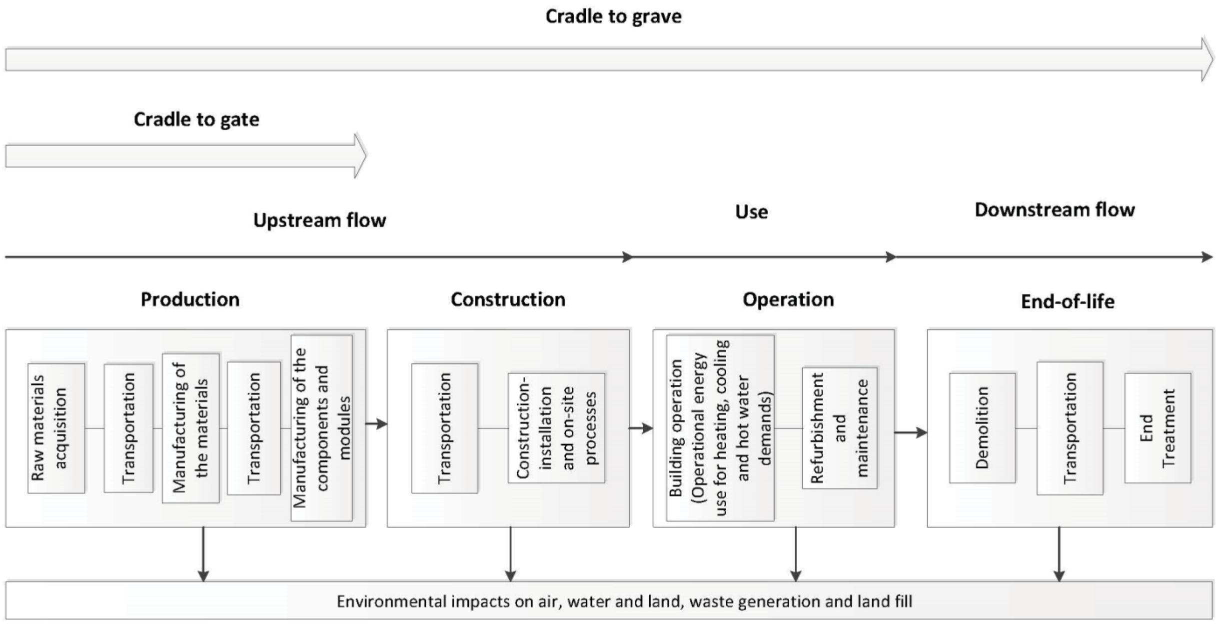

Figure 1: The life cycle stages of a building, adapted after (Khasreen et al. 2009)

The production phase refers to the required services in production of materials and components from raw material acquisition to production of the final commodities. The construction phase consists of transportation of the materials and components to the construction site and the installation services and on-site processes. Although, with current knowledge advancement in the building industry and with the increasing of the industrialized housing and prefabricated modules, the on-site construction activities are being increasingly restricted to the assembly of modules and parts. Consequently the number of gates in the production chain proliferates which results in an increase in the environmental impact in production in comparison with the construction phase. In the operation phase the environmental impacts are attributed to the operational energy demand concerning heating, cooling, domestic hot water and the refurbishment and maintenance services. Finally, the last phase is devoted to the demolition consisting of deconstruction services, transportation and the end treatment (i.e. either reuse, recycling or disposal of materials to the landfill). These life cycle phases are mainly distributed in 3 process flows, upstream (production and construction), use (operation) and downstream flow (deconstruction and disposal) (Ramesh et al. 2010).

Life Cycle Energy Analysis (LCEA)

The other form of LCA that is particularly related to the building's energy efficiency efforts is Life-Cycle Energy Analysis (LCEA) which has been evolved in the last few decades (Fay et al. 2000). The main representative factor in this method is the energy content and the environmental impacts are evaluated based on the amount of energy usage. Although, the LCEA has significantly been promoted as the environmental impact estimator in the building industry, the system boundary of this method is still unclear. Ramesh et al. (2010) define the system boundary of the building LCEA within three phases; production, operation and demolition. According to this definition, all the activities and services corresponding to the production and construction phases as well as refurbishment services of the operational phase in the building's LCA phases are incorporated in the production phase of LCEA. However, the other two phases, i.e. demolition and the operation phase except from the refurbishment activities, are the same as in LCA.

Hence, in accordance with these three LCEA phases, the building's Life Cycle Energy (LCE) and environmental impacts associated with the energy use are also being divided in three phases, embodied energy, operating energy and demolition energy. Meanwhile, other researchers as claimed by Ding (2004, cited in Dixit et al. 2010) provide a more comprehensive definition which distributes building's LCE in solely two phases, embodied energy and operating energy. In accordance with this definition the embodied energy also comprises the energy content of the demolition phase. Nevertheless, Ding (2004, cited in Dixit et al. 2010) states that the production of building materials and components off-site contributes to 75% of the total embodied energy. Whether the embodied energy includes the demolition energy or not, it contributes significantly to a buildings LCE when so-called "near zero-energy" buildings are constructed which use nearly zero or even less than zero operational energy. A case study by Hernandez & Kenny (2010) demonstrates a continual increase of the embodied energy when the building becomes increasingly energy-efficient. Thormark (2002) indicates that the embodied energy encompasses considerable part of the total energy use in the low energy buildings and its content in the low energy buildings is higher than conventional ones. In addition, Ramesh et al. (2010) state that low energy buildings perform better than self-sufficient (zero operating energy) buildings concerning the life cycle energy context since the embodied energy of the self-sufficient buildings is higher than low energy buildings. They also argue that a border in the reduction of operational energy exists where the sum of operational and embodied energy reach a minimum. Hence, with the advancement in the reduction of operating energy and achievement to the energy efficient buildings, the embodied energy of the material and components becomes a point of concern which requires more investigation to approach the concept of life cycle zero-energy buildings.

Building Information Modeling and sustainable building design

The National Building Information Model Standard Project Committee (NBIM-US 2014) defines BIM as:

Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition.

The ability of BIM in information delivery has been appreciated by the building sustainability efforts, particularly regarding the decision making in the early stages of design and planning which can significantly benefit design optimizations in terms of reduction in energy use and consequently mitigation of environmental impacts caused by the energy usage (Wong & Fan 2013; Schade et al. 2011). Kulahcioglu et al. (2012) state that assessment of the environmental performance of buildings in the design stage is crucial, since replacement of the high impact materials, which have a significant impact on the environment, is possible. Numerous approaches have been focused on the application of BIM along with BIM-based LCA and/or LCEA tools to make the building designers and architects capable to perform energy estimations and environmental impact assessment of the buildings in the early phases of the design process (Motawa & Carter 2013; Schlueter & Thesseling 2009; Azhar et al. 2011)

These BIM-based LCA/LCEA tools have been developed to assess the environmental impacts and energy use of new, existing and under refurbishment buildings, as well as building products and components. These tools cover the stages of the buildings' life cycle differently; some assess only the operational phase, some other cover one or two phases of the buildings' life cycle and further have the ability to appraise the energy consumption and environmental performance of all phases. In a study by Haapio and Viitaniemi (2008), 16 existing building environmental assessment tools are analyzed and categorized. According to this study, the associated LCA/LCEA tools for assessment of embodied energy and environmental impact related to the production of materials and components are connected to different Life Cycle Inventory (LCI) databases. These databases contain the embodied energy and impact of the building materials and therefore make this assessment possible. Some examples of these LCI databases are Oekoinventare (ETHZ), DEAM or ATHENA. Trusty and Meil (2002, cited in Haapio & Viitaniemi 2008) argue that, the comparison of the environmental impact assessment carried out by these tools is impossible due to the employment of different databases and lack of a central database. Another drawback of these energy estimation and impact assessment tools is the lack of a homogenous and unique rating system.

On the other hand, challenge in environmental performance of the building sector has led to a competition between material manufacturers to launch more eco-efficient products. Hence, manufacturers are gradually being imposed to provide relevant, verified and comparable information about the environmental impact of their commodities and services in forms of Environmental Product Declaration (EPD), a declaration reviewed by an external party and demonstrates the total embodied energy and quantity of pollutants emitted in the production of a particular product, to be able to compete with others. Nevertheless, a limited number of the LCI databases have the ability to update after the new emerged EPDs, these databases only contain an average of embodied energy and impact value of each material. Considering that each specific material is being manufactured in unique processes and different mechanisms in different factories, the outcome of the embodied energy and environmental impacts estimated by these LCA/LCEA tools is ambiguous due to the imprecise value regarding the impacts of the individual material that is being used in the specific building project.

AIM AND METHOD

Given the increasing number of the EPDs (International EPD System 2014; EPD Norway 2014) and considering that each building is unique with exclusive material and components, the aim of this research is to develop a method to assess the embodied energy and environmental impact of the building material production, by the application of BIM along with EPDs in the early stages of planning and design to enable the designers and architects to make environmentally friendlier decisions. The feasibility and obstacles of the proposed method was examined in a case study of a roof structure of a commercial built building which was constructed by off-site prefabricated roof-elements. In this study the main evaluated variables were the embodied energy and the global warming potential (GWP), i.e. embodied carbon footprint, which is one of the impact indicators considered in the environmental impact assessment of EPD. The data were gathered in collaboration with two companies, the company which manufactures prefabricated roof-elements and the company that manufactures the core constitutive material of the roof-elements i.e. the framing beams. In addition, information about delivery of the elements to the construction site was obtained through further contacts with the roof company to be able to estimate the environmental footprint associated with the transportation services.

PROPOSED METHOD

The purpose of the proposed method is to facilitate the integration of the information stored in the BIM models with the estimation and assessment of embodied energy and environmental impact from the production of material and components. The proposed method is primarily utilizing quantity take-off of the BIM materials and building parts and mapping these quantities with the constituents EPDs to assess the specific environmental impact of the design.

In this case a BIM model in native Autodesk Revit 2013 format and a Microsoft Excel 2010 sheet representing the EPDs was used. Since the environmental impact and embodied energy are set and expressed per Functional Unit (FU) in the EPDs it is crucial that the quantity take-offs of the BIM model have the same unit. When a 3D model of building is designed in Autodesk Revit, the common denominator shall be defined to make the information identifiable between the two data sets, the BIM model and the EPDs. The type mark in the 3D Revit model was used as the material and component tag in the case study.

Due to the practical and technical factors, the level of detail (LOD) of 3D objects in housing projects is generally set to element level, but given the specific purpose of this research and the tested specimen, which is a module/subassembly in the building and moreover due to the exclusive nature of the corresponding EPDs of the materials and components, the LOD is set to the material level. Hence, both the type marks in the 3D model and the Excel file containing EPDs shall be categorized and sorted out on the material level according to the corresponding EPD codes to make the information exchange feasible and detailed. The quantity take-off can be performed either by applying a BIM authoring tool e.g. Tocoman iLink or by using the schedules/quantities in the 3D Revit model. The constituents materials and components of the modules are identified on the EPD codes (i.e. type marks in the model) which later can be exported to an Excel sheet. Since the quantities in the new Excel sheet and the Excel sheet which consists of the environmental impacts and embodied energy, have same codes, the quantities can simply link to the environmental impacts and embodied energy of the materials and components and consequently the environmental footprint of the material production corresponding to the considered module can be computed. Figure 2 indicates the procedure of this proposed method.

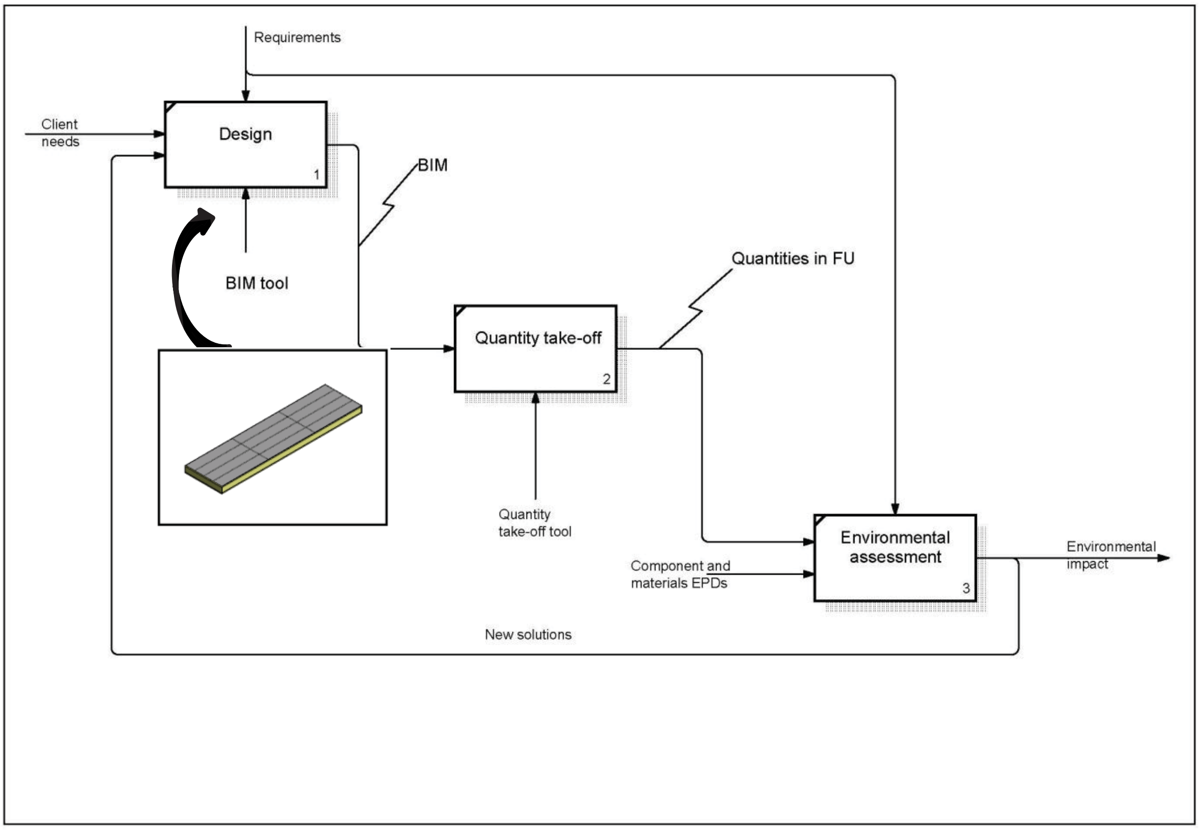

Figure 2: The proposed method to assess embodied energy and environmental impacts using BIM and EPDs.

CASE STUDY

The analysis of a roof structure

A case study was conducted to investigate the feasibility of the proposed method of environmental impact assessment and embodied energy estimation. In this study a roof structure of a commercial built building was examined. The building is a type of educational building and is located in Södertälje, south of Stockholm. The roof of the building stock was constructed from off-site prefabricated roof elements, these elements were transferred to the construction site where they were mounted together. The total surface of the roof was 1225 m^2, built by 42 off-site constructed roof elements.

The data was gathered in collaboration with two companies; the first company manufactures I-joist beams comprising flanges made from solid wood and a web made from Oriented Strand Board (OSB). The other company utilizes the I-joists as bearing structure in the construction of the roof elements and was also in charge for the implementation of the commercial building's roof, see figure 3.

Figure 3: I-joists manufactured by the first company and roof elements manufactured by the second company

Since the first company had an EPD for the I-joist beam, efforts were put into data collection on the EPDs of the constituent components in the considered roof structure. Moreover, information about delivery of the elements to the construction site was obtained through further contacts with the roof company to be able to estimate the environmental footprint associated with the transportation services. In total, six loaded truck was employed to transfer 42 roof elements to the construction site, i.e. 7 roof elements in each loaded truck. Table 1 presents materials and components being used in the manufacture of the considered roof element.

Table 1: List of constitutive materials and components in a roof element

Number	Material	Thickness	EPD	Functional Unit (presented in the EPDs)
1	Diffusion barrier paper	0.5 mm	Unavailable	Unavailable
2	Plywood board	15-17 mm	Unavailable	Unavailable
3	Glass wool insulation	400 mm	Available	Per cubic meter (m3)
4	Stone wool insulation (employed only at the edges of each element)	50 mm	Available	Per cubic meter (m3)
5	I-Joist beams (H40)	400 mm	Available	Per meter (m)
6	Coated Aluminium-Zinc sheet	0.5 mm	Unavailable	Unavailable

Quantity take-off and assessment of the embodied energy and carbon footprint

The proposed method in section four was used for the assessment of the embodied energy and carbon footprint in the case study. The embodied energy and carbon footprint of 1 m² of the considered roof element was estimated. Hence, a 3D model of 1 m² of the element was designed in Autodesk Revit using the constituent materials and components with the considered parameters in the Autodesk Revit family and subsequently loading the family components to the Revit project to design the roof element and specify the required data and attributes of the components. Whereas only three available EPDs were found (see table 1), the computed environmental declaration of the roof element by the associated company was utilized to make the assessment feasible. The energy content and carbon dioxide emissions of materials production that was presented in the company's declaration was not as accurate as the EPDs, since the EPDs are being reviewed by an external party whereas the energy content and carbon footprint of the materials in the company's declaration were carried out solely by the corresponding material manufacturer. In the case where no available data was found in the company's declaration, regarding the carbon footprint and energy content of the constituent materials, a different approach was applied. For instance, regarding the coated Aluminium-Zinc sheet, the only accessible data was a declaration of the associated manufacturer about the energy use for production of this kind of sheet. Therefore the total energy use was converted to the amount of carbon dioxide equivalents by applying the Swedish conversion factor (Svensk energi 2014). Moreover, concerning the diffusion barrier paper an EPD of a similar material from another manufacturer was employed.

As the contribution of the renewable and non-renewable energy to the total energy use is clearly stated in an EPD, no obstacles were faced to determine the embodied energy of the materials that had an available EPD. But in order to be able to compute the embodied energy of the rest of the materials, additional approaches were adopted. In the company's environmental declaration and the other product declarations which were carried out by the associated manufacturer, the total energy use was distributed to the electrical energy and fossil energy. However, the fossil energy enumerates as embodied energy, but not all content of the electrical energy, hence, more data was gathered about the electrical energy production of the associated country where the materials are

being manufactured to distinguish the proportion of non-renewable energy in the production of the electrical energy and consequently be able to estimate the total embodied energy of each individual component (Sveriges energikarta 2010).
Regarding the common denominator (i.e. type marks), in the case where no EPD existed, it was defined by the component's name. Since the computed carbon dioxide and embodied energy pertained to 1 m^2 of the roof element, the estimated values were amplified based on the total roof area to appraise the total embodied energy and carbon footprint of the implemented roof. Finally, the carbon dioxide emission associated with the transport of elements from the roof company to construction site was calculated by computing the delivery distance which was approximately 566 km and the total number and type of the truck that was utilized in the delivery (Krantz 2013).

Calculated embodied energy and carbon footprint

Figure 4 and 5 indicate the embodied energy and carbon dioxide emissions associated with the production of each constituent material in the implemented building's roof along with the transportation emissions.

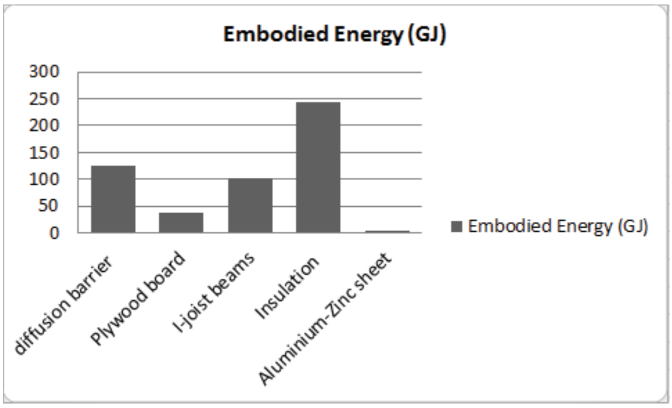

Figure 4: The embodied energy associated with the production of the constituent materials of the building's roof in the case study

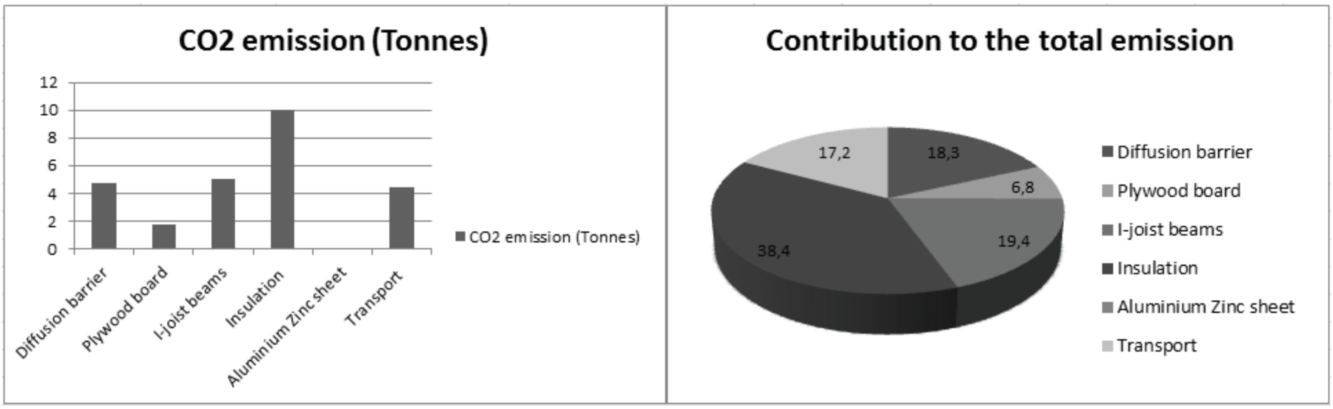

Figure 5: The corresponding carbon dioxide equivalents associated with the production of constituent materials and transportation services of the building's roof in the case study.

As shown in figure 4 and 5, the production of insulation has the highest embodied energy and consequently the largest amount of carbon dioxide emission. However, the insulation in the building's structure also reduces the energy use in the operational stage of the buildings life cycle. The next significant emitters of carbon dioxide are allocated to the production of I-joist beams and diffusion barrier, respectively. Unexpectedly, the contribution to the total carbon dioxide emissions from the transportation is not insignificant and constitutes of approximately 17 % of the total emissions. Regarding the coated Aluminium-Zinc sheet it is inferred that the presented information in the environmental declaration of the company was not considering the raw material acquisition of the ingredient materials and only included the energy use for production of this component in the factory. Aluminium has high embodied energy due to the excavation and mining processes.

DISCUSSION AND CONCLUSION

Assessment of the embodied energy and carbon footprint of the implemented commercial building's roof was demonstrated using the proposed method. Application of EPD numbers and component's name (where no EPD was available), as the common denominator facilitated the information exchange between the quantity take-off and assessment of the embodied energy and carbon footprint in the case study. Nevertheless, application of the component's name as the common denominator may not be the best choice, especially regarding assessment of the environmental impacts and embodied energy of the whole building when the number of constituent components and materials is vast. Hence, application of a system that has the ability to distinguish material and components with specific codes would be a solution regarding the lowest common denominator in this method. Currently in the Swedish construction industry a classification system called BSAB 96 (Byggtjänst 1998) is being applied in the building industry to facilitate information exchange between disciplines and actors in a project. In accordance with this system, all the building parts, elements, resources and activities are coded. Nevertheless, no attention has been set on the building materials in this system. Hence, additional approaches are required in this context. The other obstacle that was identified was the different FU in the EPDs, for instance in the I-joist beam the FU was expressed as 1 m of the component while the insulations FU was stated as 1 m^3 of the component. This variation can provide difficulties for the architects and building designers to estimate a whole building environmental impact. Hence, more research is required to investigate how the Quantity take-off should be performed to match the constituent materials and components FU of the EPDs.

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EVALUATING THE IMPACT OF CONSERVATORY AS A PASSIVE SOLAR DESIGN ON ENERGY PERFORMANCE AND INTERNAL TEMPERATURES OF UK DETACHED DWELLINGS[1]

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ABSTRACT: The prime goal of professionals in the built environment is to develop cost effective sustainable buildings which contribute to the attainment of climate change mitigation goals, facilitate the achievement of indoor thermal comfort and reduction of building energy demand. This work focuses on the viability of passive solar design strategies of UK conservatories and shows that passive solar energy utilization in building design can contribute to the reduction of dwelling energy consumption and enhancement of indoor thermal comfort. Synergetic passive design strategies that seek to optimize solar energy gains through thermal simulation analysis of design criteria of varying future climatic conditions, variable occupant behaviour, building orientation, adequate provision of thermal mass, advance glazing, appropriate ventilation and sufficient level of shading which influence the potential thermal performance of conservatory is performed. The balance energy benefits of reduction of energy consumption through the application of these principles of passive solar design for space heating in winter and the challenge of reducing excessive solar gains in summer is analysed using the CIBSE adaptive thermal comfort criteria and statistical methods of the data collected from the thermal simulation. The results show that the judicious integrated of the passive solar design strategies in conservatories with increasing conservatory size in elongated south facing orientation with an aspect ratio of at least 1.67 could progressively decrease annual energy consumption, building emission rate and annual gas consumption when the conservatory is neither heated nor air-conditioned.

Keywords: passive solar design, conservatory, energy consumption, thermal comfort, sustainability

❖ INTRODUCTION

Increasing standard of living with its associated impact on energy demand is driving the advanced nations to adopt energy and carbon emission reduction strategies in buildings (Ralegaonkar and Gupta, 2010). In the United Kingdom, studies indicate that buildings account for 30% of total energy consumption and 26% of total carbon emissions (DECC, 2011) and similar trend is observed in the Economic Co-operation and Development (OECD) countries where buildings account for between 25 to 40% of total energy consumption (Morrissey et al, 2011). This trend is also observed in the European Union (Desiseri et al. 2013). Worldwide, energy consumption for buildings is expected to increase by 45% from 2002 to 2025 (GeSI, 2008). The European Union Directive 2010/31 on the Energy Performance of Buildings seeks to influence the drive toward energy efficiency and thermal comfort optimization in buildings by mandating the transformation of all existing or new buildings to attain the set target of zero energy by 2020 (CEC 2010). Moreover, the United Kingdom Climate Change Act of 2008 outlines the UK government set target of carbon dioxide emission reduction by 34% and 80% by 2020 and 2050 respectively (DECC 2011).

Passive solar energy utilization in buildings has been a relevant design feature dating thousands of years. The archaeological findings of Anastasi Indians, Egyptians, Greeks and Romans architectural buildings point to the use of passive solar ideas in buildings during these periods of civilization (Burns and Kabak, 2014). The harnessing of the abundance and relevance of passive solar energy in building cannot be over emphasized. About 0.01% of the total amount of solar energy reaching the planet is estimated to be sufficient to meet all mankind's energy needs (BRE, 1988). The Department of Energy of the United Kingdom indicates that the amount of solar energy received by a typical dwelling in the United Kingdom in a year is more than enough compared to the total household energy consumption (BRE, 1988). Research further indicates that incorporating of passive solar

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energy design principles has the potential to contribute to about a third of the total heating needs in the UK buildings (BRE, 1988). Thus although the UK is not endowed with solar energy all year round, appropriate application of efficient passive solar designs principles could contribute significantly to the reduction of carbon emissions for current and future climate change mitigation and offer the economic benefits of reducing building thermal energy demand (Oliveira Panao et al., 2012) However, studies also indicate that lack of comprehensive and effective passive solar design strategies in buildings would rather lead to increase in household energy demand (Taleb, 2014)

Principles of Conservatory as a Passive Solar Design

A conservatory is an isolated gain passive solar system and mostly glazed enclosed space attached to one or more façade of a dwelling and serves as a thermal buffer to effect thermal and ventilation losses and also facilitates pre-heated ventilation to the main dwelling. Currently, legislation has been the main driver for buildings efficient conservatory design (Clarke et al., 2008). The UK building regulation 2010 Part L1B mandates that a conservatory will generally be exempted from the regulation if it is built at the ground level and has a floor area less than 30 square meters and the conservatory does depend on the dwelling's heating system (Planning Portal 2014). With conservatories area more than 30 square meters there must be effective thermal separation between the conservatory and the main dwelling and the conservatory should be glazed according to the standards set out in the building regulation (Planning Portal 2014) The window industry regulator of England and Wales, Fenestration Self-Assessment Scheme (FENSA) also stipulates that a conservatory must be physically separated from the main dwelling by external door and or windows and should not have less than 75% of its roof area and 50% of its wall area made from translucent material (FENSA 2014,). The Standard Assessment Procedure (SAP 2012) also directs that the u-values for conservatory building fabric, windows and doors must be similar or not more than that of the "corresponding exposed elements elsewhere in the dwelling" (BRE, 2014).

Synergetic conservatory design strategies that take into account inter-relationship of the design variables can optimize the energy balance of the dwelling resulting in energy consumption and carbon emission reductions and thermal comfort (BRE, 1988). The three fold energy balance optimization can be achieved through the design of the conservatory as efficient solar gain system, buffer or insulation effect and the control pre-heat ventilation of air passing through it to the dwelling (Mihalakakou and Ferrante, 2000). Boyle indicated in his publication that thermal buffering of south side conservatory, preheating ventilation air from the conservatory to the dwelling and solar gains contribute to 15%, 55% and 30% respectively of energy gains (Boyle, 2012). Bataineh and Fayez 2011, using numerical model to analyse the thermal performance of building attached sunspace indicated that a 42% reduction in annual heating and cooling load could be achieved (Bataineh and Fayez 2011). Research work indicates that the success of efficient solar gain system depends on complex dynamic function (Morrissey et al, 2011) of varying future climatic conditions and local topography (Lau et al., 2007), variable occupant behaviour, building orientation (Morrissey et al, 2011), adequate provision of thermal mass, advance facade glazing design, appropriate ventilation and sufficient level of shading (Ralegaonkar and Gupta, 2010). Failure holistic consideration of the design strategies may affect the efficient thermal performance of the whole dwelling.

METHODOLOGY

Background

The goal is to verify through a series of simulation using the UK Charted Institution of Building Services Engineers CIBSE Test Reference Year (TRY) and Design Summer Year (DSY) of current and future weather data which incorporates the UKCIP02 projections if the optimization of energy consumption and thermal comfort performance of habitable conservatories attached to detached dwellings stock in the United Kingdom depend on integrated passive design strategies of varying future climatic conditions, variable occupant behaviour, building orientation, adequate provision of thermal mass, advance glazing, appropriate ventilation and sufficient level of external shading using the newly developed CIBSE criteria (CIBSE TM52, 2013) as an assessment tool for both overheating and underheating conditions.

Thermal Analysis Simulation software TAS version 9.3.1, a building simulation program developed by (Engineering Development Solutions Software (EDSL, 2014), is used as a dynamic simulation modeller to model and simulate the thermal performance.

Thermal Analysis Simulation (TAS) 3D Modelling and Simulation

Building performance simulation requires the appropriate selection of modelling parameters and assumptions. The following assumptions were made in this work;

(i) Acceptability of CIBSE TRY/DSY weather data set which is based on historic data pattern to be applicable to actual weather conditions of the study building location.

(ii) Acceptability of the standardize National Calculation Methodology dwelling internal conditions activity and occupant behaviour as the prevailing conditions of the case study building.

(iii) Assuming U-values to be static instead of being dynamic as they vary with thermal and climatic conditions.

The detached dwelling used as the case study is 49 Carnation Drive; a 1995 three-bed room house located at Bracknell, Berkshire, with the latitude, longitude and time zone of 51.42 degrees North, -0.75 degree East and UTC +0.0 respectively. Bracknell, Berkshire is about 48 kilometres from Central London, the closest weather station. Hence the current CIBSE London test reference year (TRY) and design summer year (DSY) are respectively chosen for the heating season and non-heating season analysis.The thermo-physical properties of the conservatory design were selected using heuristic approach based on knowledge in building regulations, education guess, rule of thumb and experience in the use of design standards. The outputs used in the analysis are the indoor operating temperatures for thermal comfort analysis, total annual energy consumption, annual natural gas consumption and building emission rate for both the main dwelling and the conservatory.

The floor area of the main building is 115.3 square metres with a total surface area of 17.16 square metres of glazing. Four typical dwarf wall conservatory designs built at the ground floor with varying internal floor area between four (4) and thirty (30) square metres to determine the optimum design for efficient thermal performance. The conservatory design is thus within the limits specified by the UK Building Regulations which mandates a conservatory with a floor area not exceeding 30 square meters to be exempted from planning application. The maximum height for all design consideration is four (4) metres. The height of the dwarf wall is 525mm.Thermal mass specification for the conservatory dwarf wall and floor is equivalent to the PassivHaus Standard. The chosen dwarf wall design for the conservatory with its vertical thermal mass surfaces will facilitate the absorption of excess solar radiation during non-heating period and thus reduce temperature swing. Low emissivity argon filled double glazing is selected for all design consideration based on findings outlined in previous studies, for it offers the most efficient thermal performance and economic benefits as indicated earlier on in this paper. The roof and the wall of the conservatory consisted of at least 75% and 50% of glazing material respectively. The frame selected material was PVC. The conservatory fenestration dimensions were selected to meet the design criteria specified in the British Standard BS 5952:1991 and Part F of the UK Building Regulations. The conservatory is separated from the main dwelling by operable door and windows and in one scenario the conservatory was heated but never air-conditioned in all scenarios.

The data used, are the AutoCAD two-storey residential detached buildings architectural drawings of 49 Carnation Drive; figs. (1) and (2). The building drawings consisted of the ground floor and first floor plans. Detailed modelling and simulation processes using Thermal Analysis Simulation (TAS) software by Engineering Development Solutions Software (EDSL) and the modelling assumption have being clearly outlined in previous publications of the authors (Amoako-Attah and A-Jahromi, 2013), (Amoako-Attah and A-Jahromi, 2014). Figure 3 outlines the methodology used in the modelling and simulation processes. The steps include the CIBSE Guide A (2006) internal conditions specifications used in the simulation process, and the UK Building Regulation studio simulation process. The summary of the external shading and ventilation scenarios in this work are stipulated in table 1. The basis of this is optimising solar radiation gain and adequate ventilation in the dwelling throughout the seasons. Thus this work uses awnings incorporated with overhang design as external shading to control the admission of solar radiation gains. In addition, low emissivity argon filled double glazing is used for all glazed areas with an overall width of 4+16+4 and solar heat gain coefficient (SHGC or g-value) of 0.578. The low emissivity argon filled double glazing contributes to the maximization of solar gains in heating season and its mid glass panes also offers shading effect to mitigate overheating. Moreover, vertical conservatory glazing design consideration was selected instead of sloped glazing to minimize overheating.

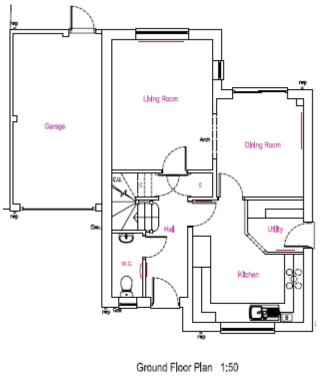

Fig. 1 Ground Floor Plan

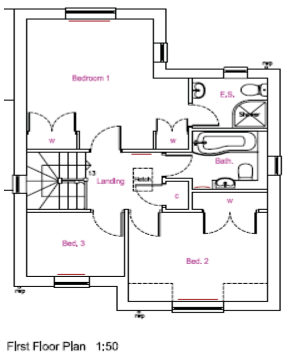

Fig. 2 First Floor Plan

Fig 3. Methodology for modelling and simulating

Table 1. Modelling and Simulation Parameters and Assumptions

Modelling assumptions and parameters

		Non Heating Season		Heating Season	
		Day	**Night**	**Day**	**Night**
Day lighting		Clear Sky Accuracy - Reflectance convergence for detailed analysis	N/A	Overcast Sky Accuracy - Reflectance convergence for detailed analysis	N/A
Weather Data		DSY	DSY	TRY	TRY
Ventilation	*Scenario 1*	Adequate Cross ventilation in all direction, Openable window proportion 100%; at least 5% of total floor area. Set openable window temperature 20°C-21°C. Openable window Schedule 4am - 8pm	N/A	Optimum Cross ventilation between conservatory south facing fenestration and main building north fenestration, Openable conservatory lower/bottom window proportion 25% . Openable main building north facing window proportion 5% Set conservatory openable window temperature 10°C-11°C, main building 20°C-21°C Openable window Schedule 10am - 3pm	Doors/windows between conservatory and main building CLOSED. Conservatory serve as buffer
	Scenario 2	Adequate Cross ventilation in all direction, Openable window proportion 100%; at least 5% of total floor area. Set openable window temperature 20°C-21°C. Openable window Schedule 24 hrs	Adequate Cross ventilation in all direction, Openable window proportion 100%; at least 5% of total floor area. Set openable window temperature 20°C-21°C. Openable window Schedule 24 hrs	Optimum Cross ventilation between conservatory south facing fenestration and main building north fenestration, Openable conservatory lower/bottom window proportion 25% . Openable main building north facing window proportion 5% Set conservatory openable window temperature 10°C-11°C, main building 20°C-21°C Openable window Schedule 10am - 3pm	Doors/windows between conservatory and main building CLOSED. Conservatory serve as buffer
	Scenario 3	Adequate Cross ventilation in all direction, Openable window proportion 100%; at least 5% of total floor area. Set openable window temperature 20°C-21°C. Openable window Schedule 24 hrs	Adequate Cross ventilation in all direction, Openable window proportion 100%; at least 5% of total floor area. Set openable window temperature 20°C-21°C. Openable window Schedule 24 hrs	Optimum Cross ventilation between conservatory south facing fenestration and main building north fenestration, Openable conservatory lower/bottom window proportion 25% . Openable main building north facing window proportion 5% Set conservatory openable window temperature 10°C-11°C, main building 20°C-21°C Openable window Schedule 10am - 3pm	Doors/windows between conservatory and main building CLOSED. Conservatory serve as buffer
Shading	*Scenario 1*	No shading	N/A	N/A	Internal shading device coupled with coated low-e double glazed
	Scenario 2	Roof (overhang/awnings) and south facing conservatory side shading South shading schedule 10am – 3pm	N/A	N/A	Internal shading device coupled with coated low-e double glazed
	Scenario 3	Roof (overhang/awnings), south, east and west facing conservatory sides shading East shading schedule 4am - 11am West shading schedule 12 noon - 8pm	N/A	N/A	Internal shading device coupled with coated low-e double glazed

RESULTS AND DISCUSSION

The analysis of case study building , 49 Carnation Drive; a 1995 three-bed room two-storey residential detached building located at Bracknell, Berkshire, with the three conservatory designs is presented below. Figs. 4 (a) and (b) represent the outcome of the modelling process. The entire major façade of the conservatories was southerly orientated with an aspect ratio of at least 1.67.

Fig. 4(a) 49 Carnation Drive – South facing orientation

Fig. 4(b) 49 Carnation Drive and Conservatory 1

Fig. 4 Modelling Results

Energy performance results and analysis

Fig. (5) gives the statistical results of energy performance of annual energy consumption, building emission rate and annual natural gas consumption for the current and future weather data set for all three conservatory design scenarios. The annual energy consumption results indicated show an observable decrease in energy consumption for all the three conservatory designs in scenario 2; when the attached conservatory to the main building is unheated throughout the heating season. The declining trend is observed in the respective climate change progression timelines of current, 2020s, 2050s and 2080s for all conservatory designs. The mean percentage decrease of annual energy consumptions for conservatory 1 to 3 was 12.17, 14.23 and 21.45 respectively and these amounts to 3.98, 4.72 and 7.13 kWh/m^2 respectively. This declining trend points to a general decrease in annual energy consumption with progressive increase in conservatory floor area/surface area and indicates a significant contribution to dwelling energy consumption when a conservatory is attached to it. At periods of low air temperatures coupled with high solar radiation, pre-heated air in the conservatory is transferred to the main dwelling. This convective heat gain leads to the reduction of the main building heat load contribution form a mechanical heating system. In addition, increasing the conservatory dimension along the southern orientation contributes to the provision of additional insulation of the main dwelling. This increasing buffer effect results in a decrease in heat loss from the main dwelling

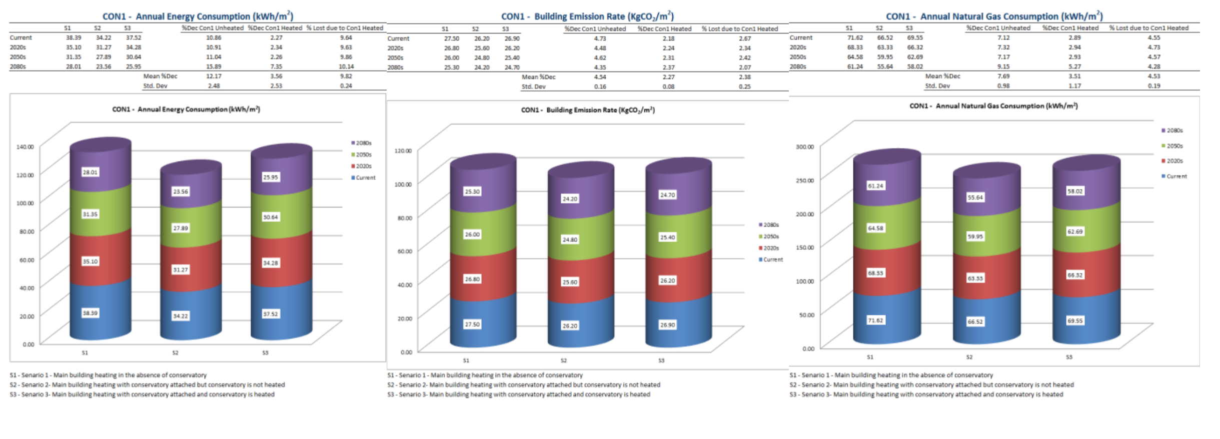

Fig 5 Conservatory 1 – Annual Energy Consumption (kWh/m^2), Building Emission Rate (KgCO$_2$/m^2) and Annual Natural Gas Consumption (kWh/m^2)

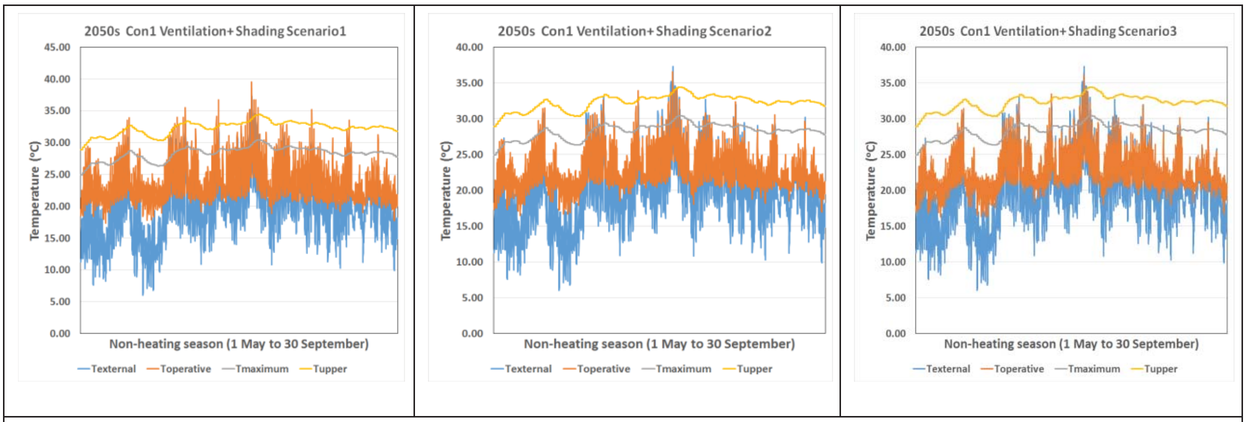

Fig. 6 2050s weather conservatory non-heating season analysis

and hence reducing its heating load. At the same time, the progressive increase of the elongated south façade of the conservatory with its coated low emissivity double glazing coupled with the effective design of awnings/overhang which maximize the incident solar radiation collection during the heating season, low level ventilation and the provision of adequate thermal mass for the conservatory floor and dwarf walls all contribute to the passive design consideration leading to the reduction of heating load of the main dwelling.

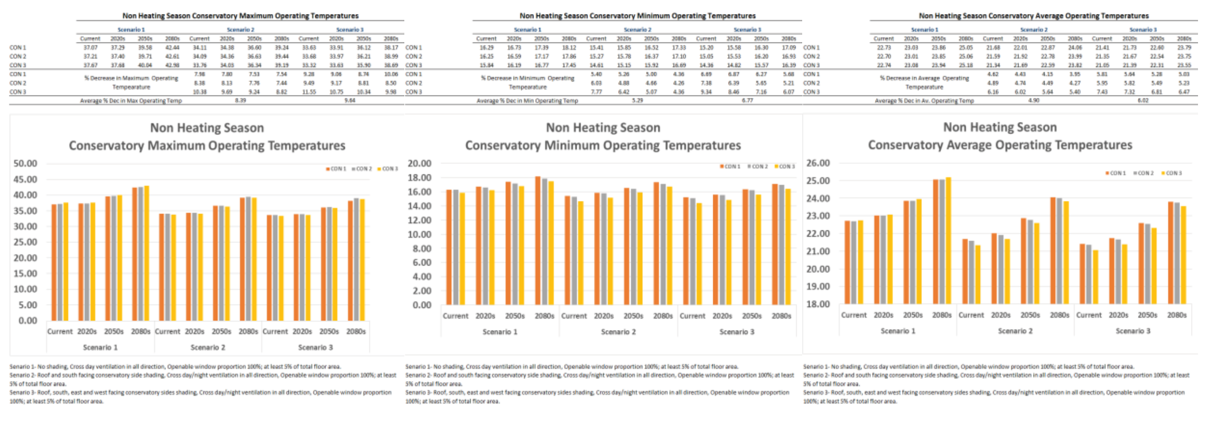

Fig 7. Non heating season conservatory maximum, minimum and average operating temperatures

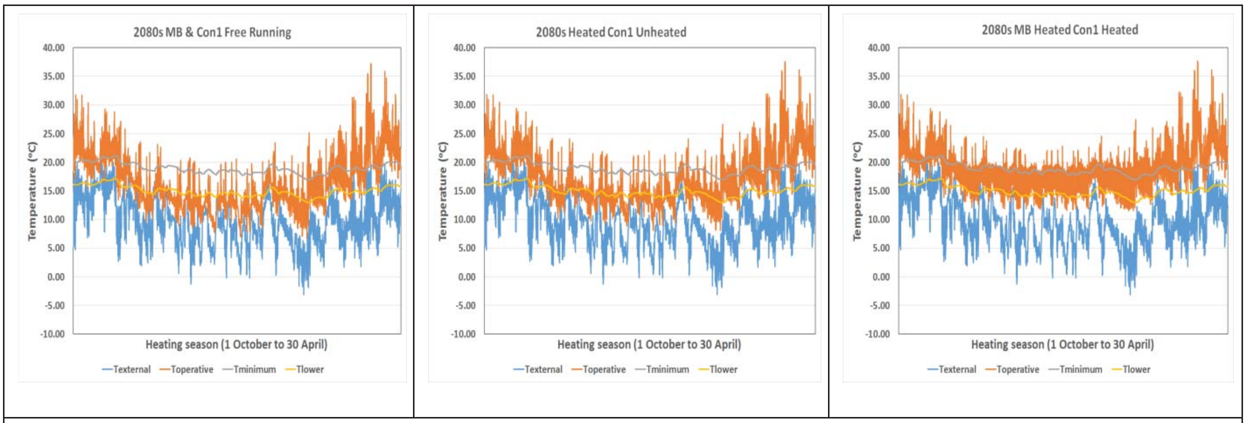

Fig. 8 2080s weather conservatory heating season analysis

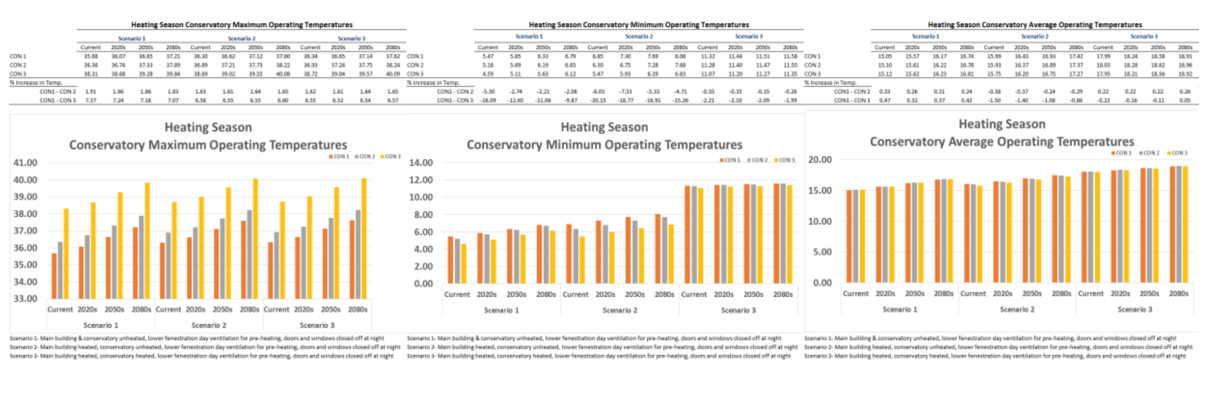

Fig 9. Heating season conservatory maximum, minimum and average operating temperatures

However, the annual energy consumption gains are negated in scenario 3 when the conservatories are heated during the heating season. The mean percentage of annual energy consumption lost due to the heating of the three conservatories was observed to be 9.82, 16.63 and 29.99 for the current and future weather data set. This trend points to increasing loss of overall annual energy consumption with increasing conservatory dimensions when the conservatories are heated during the heating season.

The building emission rate results show an observable decrease in emission rate for all the three conservatory designs in scenario 2; when the attached conservatory to the main building is unheated throughout the heating season. The declining trend is observed in the respective climate change progression timelines of current, 2020s, 2050s and 2080s for all conservatory designs. The mean percentage decrease of building emission rate for conservatory 1 to 3 was 4.54, 6.62 and 11.07 respectively and these amounts to 1.20, 1.75 and 2.93 $KgCO_2/m^2$ respectively. This declining trend points to a general decrease in building emission rate with progressive increase in conservatory floor area/surface area and indicate a significant contribution to dwelling emission rate when a conservatory is attached to it. The reasons for the declining trend could also be ascribed to the reasons outlined earlier on in relation to the declining trend associated with the annual energy consumptions. Nevertheless, the building emission rate gains are also negated in considering scenario 3 when the conservatories are heated during the heating season. The mean percentage of building emission rate lost due to the heating of the three conservatories was observed to be 2.38, 4.25 and 7.22 for the current and future weather data set. The annual gas consumption results show an observable decrease in gas consumption for all the three conservatory designs in scenario 2; when the attached conservatory to the main building is unheated throughout the heating season. The declining trend is observed in the respective climate change progression timelines of current, 2020s, 2050s and 2080s for all conservatory designs. The mean percentage decrease of annual natural gas consumption for conservatory 1 to 3 was 7.69, 9.88 and 14.56 respectively and these amounts to 5.08, 6.57 and 9.69 kWh/m^2 respectively. This declining trend points to a general decrease in annual gas consumption with progressive increase in conservatory floor area/surface area and indicate a significant contribution to dwelling annual natural gas consumption when a conservatory is attached to it. There reasons for the declining trend could again be ascribed to the reasons outlined earlier on in relation to the declining trend associated with the annual energy consumptions. Again, the gains attributed to the annual natural gas consumption in scenario 2 are also negated in consideration of scenario 3 when the conservatories are heated during the heating season. The mean percentage of building emission rate lost due to the heating of the three conservatories was observed to be 4.53, 7.99 and 13.73 for the current and future weather data set.

Thermal comfort overheating results and analysis

Fig. (6) shows a synopsis of the CIBSE TM52 thermal comfort overheating analysis results for the non-heating season of the three conservatory designs based on the earmarked simulated ventilation and shading scenarios for the current and future weather data set. The results show that the use of awnings/overhangs to block excessive solar radiation during the non-heating period coupled with night time ventilation as specified in scenario 2 could offer a significant reduction of operating temperatures to enhanced thermal comfort. A further reduction in the trend is realised in scenario 3, when additional shading is provided to the east and west facades of the conservatories. Fig. (7) shows analysis of the operating temperatures of the three conservatory designs for specified ventilation and shading scenarios during the non-heating season for the current and future weather data set.

Thermal comfort underheating results and analysis

Fig. (8) shows a synopsis of the modified CIBSE TM52 thermal comfort underheating analysis results for the heating season of the three conservatory designs based on the specified simulation ventilation and heating scenarios for the current and future weather data set. In general, the PassivHaus standard thermal mass for the floor and dwarf walls coupled with the coated low emissivity double glazing effect a moderate operating temperature swing to a degree when compared to a conservatory design which neglects passive solar design principles. The results for scenarios 1 and 2 indicate noticeable operating temperature swing during the heating season for all weather data set consideration. This limits the use of conservatory as a thermally comfortable living space. The scenario 3; where the conservatories are heated together with the main dwelling obviously results in moderate swings, which suggest that conservatories could provide thermal comfort when heated. However, this is not is consonance with the energy balance of the use of conservatory as a passive solar design. Heating conservatories negates the energy and thermal performance gains with increase in energy consumption, building emission rate and annual natural gas consumption. The variability of high operating temperatures for late spring and early autumn suggest that strategic passive provision of shading and ventilation must be in place during this period. Fig. (9) shows analysis of the operating temperatures of the three conservatory designs for specified ventilation and heating scenarios during the heating season for the current and future weather data set.

CONCLUSION

The study evaluated the impact of conservatory as a passive solar design on three key dwelling energy performance indicators of annual energy consumption, building emission rate and annual natural gas consumption of UK detached dwellings. An investigation of internal temperatures was also done using CIBSE adaptive thermal comfort methods to access the overheating and underheating of conservatories. Thermal analysis simulation based on the synergetic passive design strategies that seek to optimize solar energy gains through the varying future climatic conditions based on CIBSE weather data set, variable occupant behaviour, building orientation, adequate provision of thermal mass, advance glazing, appropriate ventilation and sufficient level of shading which influence the potential thermal performance of conservatory was performed on three conservatories with varying sizes. The simulation results showed that the integration of passive solar strategies in conservatory design could significantly decrease energy consumption, building emission rate and natural gas consumption. The amount of percentage decrease was inversely proportional to the increase of conservatory size when the increment is done along the southern orientation of the building facade. This increase in conservatory southern façade dimension facilitated the increase in solar radiation gains during the heating season and also offered a thermal buffer effect. The balanced energy benefits by pre-heating of the main building by means of conservatory does not necessarily replaced the mechanical heating systems, but the process offers a noticeable decrease in the thermal performance parameters when the conservatory is not heated during the heating season. The investigations also indicated that the provision of optimum ventilation strategy depending on the period of the year coupled with the efficient design of awnings/overhangs and the provision of external adjustable shading on the east and west facades of the conservatory could significantly enhance the thermal comfort of conservatories.

The utilization of passive solar design has virtually no negative impact to the environment as it does not use any form of operational energy to provide thermal comfort and also does not incur operational cost. Rather a holistic passive solar design which takes cognisance of passive solar principles offers a significant reduction for energy demand and building emission rate. However, passive solar design solutions are underpinned by variable occupant behaviour. Thus, the incorporation of smart house technological solutions such as automatic external shading and demand control ventilation strategies could enhance the design intent of the application of the passive solar principles. This work has shown the potential of conservatories to serve as an effective passive solar design which can significantly offer a positive contribution to the energy performance and enhancement of thermal comfort of a dwelling, when passive solar design principles are applied and the conservatory is neither heated nor air-conditioned. Thus this work indicates that passive solar design of conservatories through thermal analysis simulations offers a viable solution of reducing dwelling energy consumption, climate change emissions and natural gas consumption and thereby contributes to environmental sustainability achievements.

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REAR-SCREEN AND KINESTHETIC VISION 3D MANIPULATOR[1]

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ABSTRACT: *The effective 3D manipulation, comprehension, and control of 3D objects on computers are well-established lasting problems, which include a display aspect, a control aspect, and a space coupling between control input and visual output aspect, which is a debatable issue. Most existing control interfaces are located in front of the display. This requires users to imagine that manipulated objects that are actually behind the display exist in front of the display. In this research, a Rear-Screen and Kinesthetic Vision 3D Manipulator is proposed for manipulating models on laptops. In contrast to the front-screen setup of a motion controller, it tracks a user's hand motion behind screens, coupling the actual interactive space with the perceived visual space. In addition, Kinesthetic Vision provides a dynamic perspective of objects according to a users' sight, by tracking the position of their head, in order to obtain depth perception using the "motion parallax" effect. To evaluate the performance of "rear-screen interaction" and Kinesthetic Vision, an experiment was conducted to compare the front-screen setup, the rear-screen setup with Kinesthetic Vision, and the rear-screen setup without it. Subjects were asked to grasp and move a cube from a fixed starting location to a target location in each trial. There were 20 designated target locations scattered in the interactive space. The moving time and distance were recorded during experiments. In each setup, subjects were asked to go through 5 trial blocks, including 20 trials in each block. The results show that there are significant differences in the moving efficiency by repeated measures ANOVA. The Rear-Screen and Kinesthetic Vision setup gives rise to better performance, especially in the depth direction of movements, where path length is reduced by 30%.*

KEYWORDS: *3D manipulator, virtual reality, rear-screen, kinesthetic vision, eye-hand coordination.*

❖ INTRODUCTION

3D computer graphics technology allows people to display 3D models on computers. As the technology advances, it has become widely used in various industries including animation, gaming, and computer-aided design. However, the limitations of display and control devices still introduce difficulties when comprehending and interacting with 3D models. Further, the space coupling between a perceived visual location and manipulating locations of models is still a debatable issue.

The first issue is the two-dimensional limitation of display devices. Although models are in three dimensions, it is still difficult to present them using stereoscopy. To make models "pop out" of screens, 3D viewers common use the technique of presenting two offset images separately in different eyes, requiring extra head-worn devices. Another way to enhance stereoscopic perception is by using "motion parallax" effects, which is the relative displacement of viewed models by changing observers' positions [1].

The second issue is the limitation of control devices. Dominant 2D input devices, which allow fine control of two-dimensional motion, are inappropriate for 3D manipulating due to the limited number of degrees-of-freedom (DoF). As a result, a mouse with virtual controllers for 3D manipulating has been discussed and evaluated in conjunction in several previous studies [2,3]. To overcome the limited DoF, controllers with three or more DoF are also developed for enhancing usability in 3D interactions [4].

The last issue is coupling between control input and visual output spaces. Humans process visual cues received from eyes and proprioception from hands guide the movements of hands to reach and grasp models; this is called eye-hand coordination [5]. Good eye-hand coordination can reduce the mental burden during manipulation. However, most motion controllers decouple the perceived visual space (which is behind the display) and interactive space of models in front of the display. Some people consider that, although this method follows the usual method of computer use, it may separate eye-hand coordination. Users' brains need to make a semi-permanent adjustment of the spatial coupling between these spaces [6]. This adaptation leads to negative after-effects of eye-hand coordination [7]. To discuss these issues, some related works about spatial coupling problems are reviewed in the next section.

[1] Citation: Yang, C. C., Yang, H. W., Wu T. H. & Kang, S.C. (2014). Rear-screen and kinesthetic vision 3D manipulator. In: N. Dawood and S. Alkass (Eds.), Proceedings of the 14th International Conference on Construction Applications of Virtual Reality, 16-18 November 2014, Sharjah, UAE.

Related Work

In previous research, there have been two kinds of interaction methods to solve the problem of spatial coupling.

Immersive Display

Head-mounted displays (HMD) immerse users in the virtual environment. As a result, all visual perception of space is virtual, and the coupling problem no longer exists. HMD are widely used in virtual environment navigation. Newton et al. proposed the Situation Engine, which combines simulated environment with HMD and gestural control, to provide a hyper-immersive construction experience [8]. However, the disadvantage is that it is relatively expensive, and it is not appropriate for extended use because it can cause dizziness and there is a need to coordinate between the virtual space and real input space [9]. Also, it focuses on large-scale 3D environment exploration rather than the manipulation of models.

Existing Rear-Screen Interaction

Another method is to "partially" bring users into a virtual environment. The method combines Augmented Reality (AR), which fuses virtuality and reality, and the rear-screen setup, making users enter the environment visually. Kleindienst invented a viewing system for object manipulation, by coinciding the manipulation spaces as well as the real and virtual spaces in the viewing device [10]. Holodesk, combining the optically transparent display with a Kinect camera for sensing hand motion, makes users interact with 3D graphics directly [11]. Using the same concept, SpaceTop with the transparent OLED display is a desktop workspace that makes it easy for users to interact with floating elements on the back of the screen [12]. The rear-screen idea is also brought to touch-screen devices for preventing fat-finger problems [13]. In this contribution, we emulate a "rear-screen" using a simple setup, a laptop, and a motion controller, and compare the efficiency and fatigue of "rear-screen" and “front-screen” tasks.

REAR-SCREEN AND KINESTHETIC VISION 3D MANIPULATOR

In this research, we proposed the rear-screen and kinesthetic vision 3D manipulator with a simple physical setup. Users are able to manipulate 3D models behind computer screens. Using the proposed method, the "Real Space Virtual Reality" makes the perceived virtual space and real interactive space coincident. We introduce the details of the research in this section, which is divided into the input and output modules: Rear-Screen Interaction and Kinesthetic Vision.

Rear-Screen Interaction

In the virtual environment, virtual simulated hands are constructed in the same dimension and position with real hands behind the screen. Users enter their hand into the virtuality and interact directly with 3D models (Fig. 1). The models in the virtuality should be constructed in the correct dimensions by referencing the scale between the virtual eye coordinates and the actual eye coordinates.

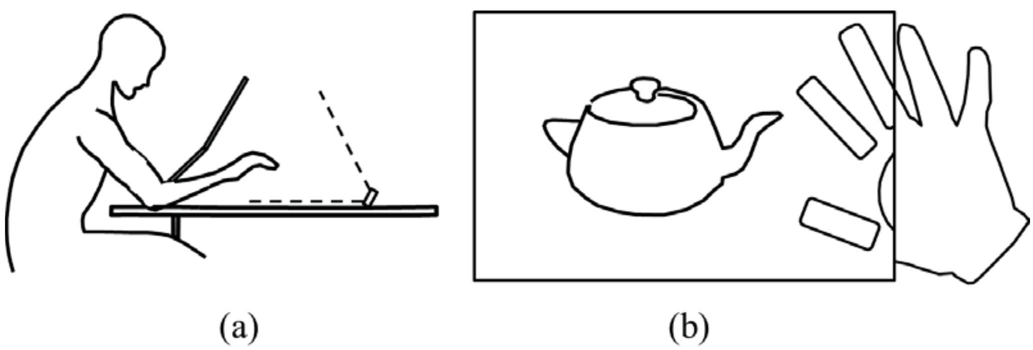

Figure 1. Schematic of Rear-Screen Interaction:
(a) Side View of the Physical Setup and (b) Screen View

Kinesthetic Vision

Positions Synchronizing between Virtual and Actual Eyes

The purpose of this part is to present the appropriate virtual scene by synchronizing the actual and virtual eye positions (Fig. 2). When the virtual and actual eyes move simultaneously, the relative displacement of the viewed objects, the so-called "motion parallax", provides a visual depth cue.

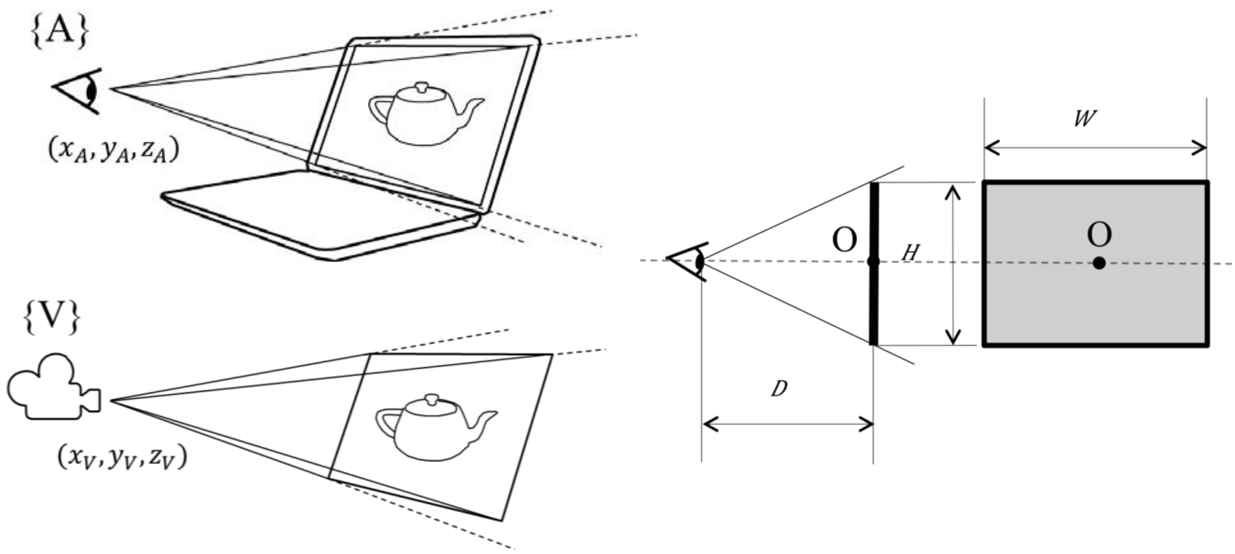

Figure 2. Actual and Virtual Eye Positions

$$x_V = \frac{W_V}{W_A} \cdot x_A \qquad (1)$$

$$y_V = \frac{H_V}{H_A} \cdot y_A \qquad (2)$$

$$z_V = \frac{D_V}{D_A} \cdot z_A \qquad (3)$$

x_V, y_V, z_V is the position of the virtual eyes and x_A, y_A, z_A is the position of the actual eyes. The coordinate origin is at the center of the screen and the near plane. W_V is the width of the near plane, and W_A is the width of the screen view. H_V is the height of the near plane, and H_A is the height of the screen view. D_V is the distance from of the virtual eye coordinates origin to the near plane center, and D_A is the distance from of the actual eye coordinates origin to the screen center.

Frustum Calibration

In order to simulate the shape of the actual viewing frustum through a virtual frustum, the position of the user's eyes relative to the monitor is required. In Fig 3 r, l, t, b, and n are position parameters of the near clipping plane relative to the local eye coordination. Parameter f is the distance from the far clipping plane to the coordination in the z-direction; it is set to infinity. As the eyes move, the above parameters will be changed and need to be substituted into equation (4) of the projection matrix.

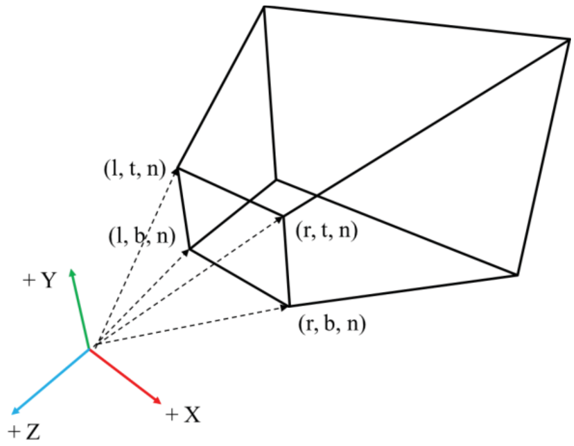

Figure 3. Definition of the perspective projection parameters

$$M = \begin{pmatrix} \frac{2n}{r-l} & 0 & \frac{r+l}{r-l} & 0 \\ 0 & \frac{2n}{t-b} & \frac{t+b}{t-b} & 0 \\ 0 & 0 & \frac{-(f+n)}{f-n} & \frac{-2fn}{f-n} \\ 0 & 0 & -1 & 0 \end{pmatrix} \quad (4)$$

IMPLEMENTATION

The Rear-Screen Interaction and Kinesthetic Vision will be further introduced in this section by dividing into three parts: physical setup, software setup, and demonstration.

The Physical Setup

Three devices—a laptop, a webcam and a motion controller—are used. These have the advantage of being readily accessible and easy to set up. The laptop is a Lenovo X220 with 12.5" monitor, dual-core 2.3 GHz CPU and Intel HD Graphics 3000. A Logitech S5500 webcam is used for mark tracking. The webcam is set up behind users. Users are required to wear a red cap as a head tracking mark. A Leap Motion controller is a computer sensor device which detects the motions of hands, fingers and finger-like tools as input, and the Leap Motion API allow developers to obtain tracking data for further use [14] (Fig. 4).

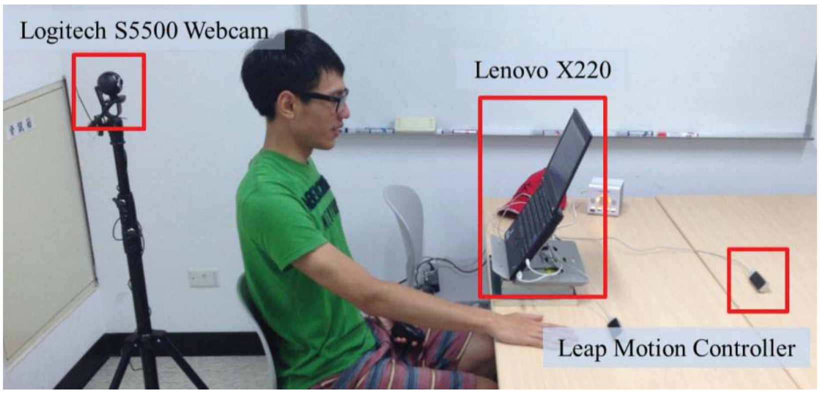

Figure 4. Physical Setup

The Software Setup

The Unity game engine is chosen to construct the game environment, developed in C#. OpenCV libraries are used to implement the mark tracking function, and are integrated with Leap Motion API.

System Demonstration

We constructed a realistic environment similar to the real environment behind the screen, and kinesthetic vision was implemented to provide the correct perspective (Fig. 5).

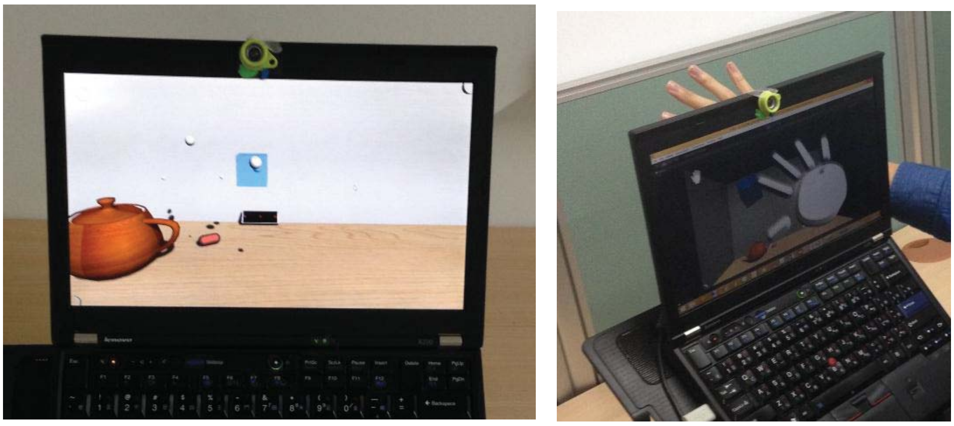

Figure 5. Rendering Results of Kinesthetic Vision and a Simulated Hand

EXPERIMENTS AND EVALUATION

This section will introduce the experimental method for performance evaluation, including experiment procedures, participants, and performance measurement methods.

Experiment Design

We set three conditions to compare the performance of our rear-screen setup and standard setups: Rear-Screen Interaction with Kinesthetic Vision (RIK), Rear-Screen Interaction (RI), and Front-Screen Interaction (FI). By comparing RIK and RI, we attempt to ascertain if the motion parallax effect is effective for depth perception. Likewise, RI is compared with FI to confirm the superiority of rear- to front-screen in eye-hand coordination.

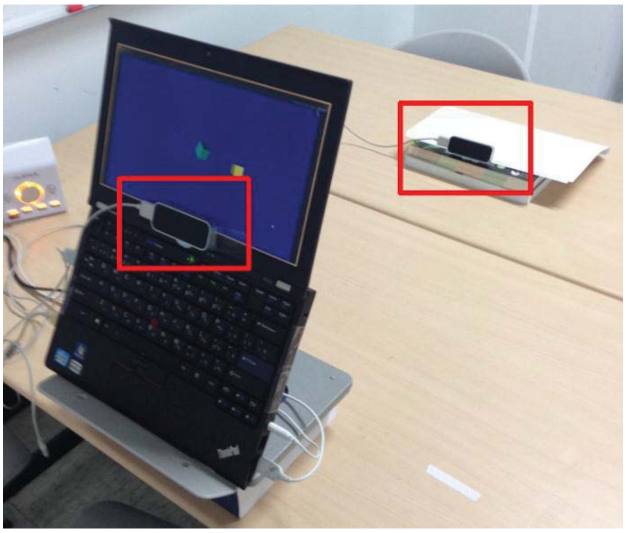

Figure 6. Front-Screen Setup and Rear-Screen Setup

Participants

We recruited 12 participants for the experiments. All participants are male and ranged from 22 to 25 years of age. The participants are right-handed and have normal vision. They were also required to have at least 6 months' experience using software with 3D models manipulation functions, such as SketchUp, Revit, and Unity3D.

Procedures

Phase I: Introduction and Preliminary Practice

First, users are introduced the overview of the experiment, including the physical setup and the software setup. Then, participants are required to practice the grab, release and move actions. The most important aim of this section is to make the user familiar with the setup and control device, avoiding subjective factors.

Phase II: Formal Test: Moving Objects

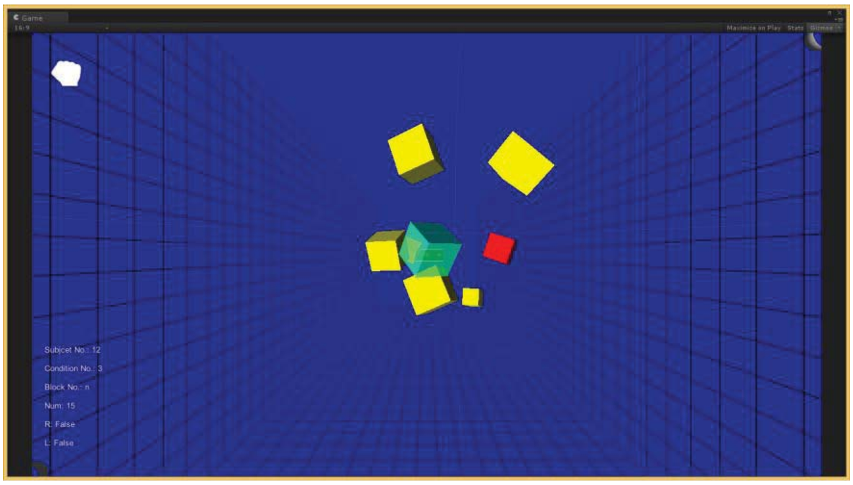

Figure 8. Experiment Software Setup

Users are asked to grab and move a green cube (starting position) to a red cube (target position) in a trial. The interaction depth is about 60 cm. Starting and target positions are coupled beforehand to avoid in-condition variance with random orders. 5 yellow cubes appear in random positions to avoid temporary position memory.

Each user has to conduct 3 sets of tasks according to the 3 aforementioned conditions. Each set of tasks are divided into 5 blocks and each block contains 20 trials.

Phase III: Formal Test: NASA-TLX

Last, participants conduct the NASA Task Load Index (NASA-TLX)[15], coupled with the fatigue scale and the overall scale after each set.

Each condition takes about 30 minutes, including rest time between each block for fatigue prevention. After the quantitative test, we interview users about their impressions to obtain qualitative results.

Performance Measurement

Zhai reported six basic aspects to the usability of a six DoF input device: speed, accuracy, ease of learning, fatigue, coordination, and device persistence and acquisition [16]. Excluding device persistence and acquisition, which is not applicable here, we describe the method for qualitatively measuring each of the above aspects to evaluate the performance of the rear-screen kinesthetic 3D manipulator.

- Speed: The task completion time is divided into 2 periods: the object acquisition time and the object moving time. The measurement of the acquisition time is triggered once the virtual hand is visualized, and ends once the user grabs the object. The moving time is triggered once the user grabs an object, and ends once the object reaches the target location and the space bar is subsequently pressed.
- Accuracy: When the user presses the space bar, the distance between the centers of the object and the target is measured.
- Ease of learning: We compare the performance between blocks of trials to evaluate whether the user improves by measuring the slope of the regression line between blocks of trials.
- Fatigue: We reference the scaling of NASA-TLX to rate the fatigue.
- Coordination: The ratio between actual trajectory length and the most efficient trajectory length is measured. In our design, the most efficient trajectory is the straight-line distance between two objects. The lengths in the x, y, and z-directions are also recorded.

RESULT

Table 1 shows only two significant differences between setups of most of the usability aspects according to repeated measures ANOVA: Coordination ($F(2, 22) = 3.919$, $*p < 0.05$) and Grab time ($F(2, 22) = 4.157$, $*p = 0.029 < 0.05$). When we visualize Grab time differences between FI, RI, and RIK (Fig 9.), the figure indicates that the real significance is between FI and RI, but not RI and RIK. This matches our expectations. Under the RIK conditions, participants move left and right in order to distinguish the depth, however their hand is still outside of the screen. As a result, participants cannot distinguish the position of their hand with respect to the green box.

Table 1: Significance of usability aspects by repeated measures ANOVA

Performance		Significance
Speed	**Grab Time**	**.029**
	Moving Time	.550
Ease of Learning	Grab Time	.303
	Moving Time	.311
	Coordination	.860
Fatigue		.675
Coordination		**.035**

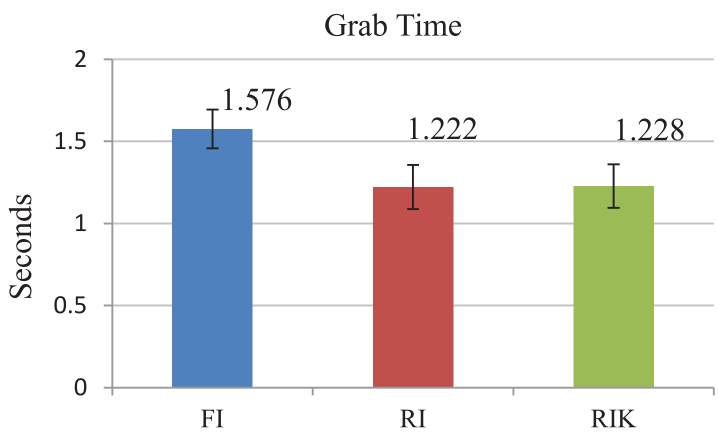

Figure 9. Grab time for Front-Screen Interaction (FI), Rear-Screen Interaction (RI) and Rear-Screen Interaction with Kinesthetic Vision (RIK) Variants of the rear-screen and kinesthetic vision 3D manipulator. (Error bars represent +/- SEM.)

In Fig. 10(a), in accordance with our expectations, RIK has a better ratio than RI, and RI also has a better ratio than FI. However, these ratios only range from 0.503 to 0.556, which does not show obvious significance. Consequently, we focus on coordination in the z-direction, according to our research goal. In Fig. 10 (b), the differences of coordination in the z-direction for the three conditions are highly significant according to repeated measures ANOVA ($F(2, 22) = 27.751$, $**p < 0.001$.). The rear-screen interaction with kinesthetic vision has the most efficient z-direction trajectory ratio (0.597), followed by one without kinesthetic vision (0.549) and the front-screen interaction (0.453). Also, post-hoc pair-wise comparisons (Bonferroni-corrected) showed significant differences between all conditions ($p < 0.05$).

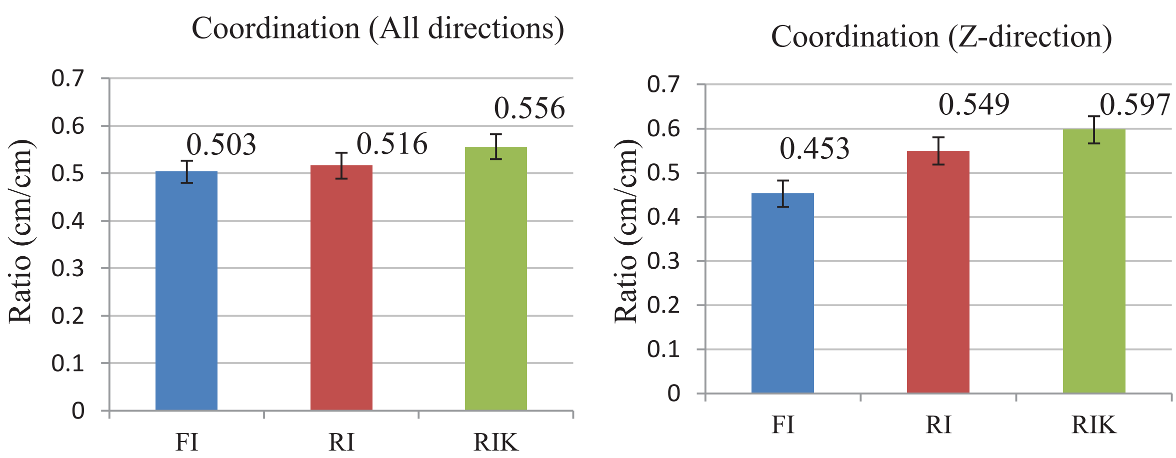

Figure 10. Coordination ratios across the Front-Screen Interaction (FI), Rear-Screen Interaction (RI) and Rear-Screen Interaction with Kinesthetic Vision (RIK) Variants of the rear-screen and kinesthetic vision 3D manipulator:
(a) Coordination in all directions; (b) Coordination in the Z-direction. (Error bars represent +/- SEM.)

DISCUSSION

No Significant Difference in Speed

Surprisingly, the object move time shows no significant difference between the three conditions ($p > 0.01$). We observed that movement speed varies according to personal habits.

Distraction and Difficulties in Eye-Hand Coordination

From users' feedback in the interviews, we learned users are prone to be distracted by the virtual and actual hands in the FI setup. As a result, the user finds it difficult to explore in the depth direction, leading to less efficient trajectories.

Application

Design Review

Design review (DR) is a critical control point throughout the product development process to evaluate a design against its requirements. The process requires several rounds of 3D manipulation in order to comprehend a design in sufficiently great detail. Also, depth perception is crucial for exploring in a 3D virtual environment.

Gaming

Eye-hand coordination, i.e. visuomotor coordination, plays an important role in playing video or computer games [17]. Players must respond accurately and quickly to visual information. Coupling between virtual and real spaces reduces the extra effort required for spatial adaption.

CONCLUSION

We propose a rear-screen and kinesthetic vision 3D manipulator, which is a novel 3D object manipulation method with a simple setup. Users are allowed to interact with a virtual object directly behind the screen. The components of the rear-screen and kinesthetic vision 3D manipulator are described and implemented in this research. Finally, experiments are conducted to evaluate the design.

The experimental results show there is a significant difference in coordination in the z-direction between FI, RI and RIK. Therefore, objects whose trajectory is in the depth direction are more efficiently manipulated using the rear-screen and kinesthetic vision 3D manipulator than using the standard setup. In general term, the kinesthetic sense improves users' depth perception. The finding shows the possibility and value of installing sensors for use in the design review and gaming domains.

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ASSESSING WATER PIPELINES PERFORMANCE USING ACYCLIC SIMULATION[1]

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ABSTRACT: *Because water is scarce and precious in Qatar, its preservation is a strategic goal for the local government. The preservation of water in Qatar is not an easy task because of its 5,400-kilometer-long pipeline network. Water pipelines deteriorate faster with age due to several internal and external factors, which lead ultimately to their failure. Pipeline failure can lead to significant waste of precious water and can also endanger public health, safety, and environment. To minimize the risk of pipeline failure, water pipelines need to be periodically inspected and maintained. Unfortunately, the budget of pipeline inspection and maintenance for municipalities and water agencies is limited. Therefore, there is a real need to develop reliable performance assessment models for the optimum planning of the inspection and maintenance of water pipelines. These assessment models help municipalities plan for water pipeline inspection, maintenance, and rehabilitation actions to ensure an adequate supply of water in a safe, cost-effective, reliable, and sustainable manner. Several models were developed to assess the performance of water pipelines. However, limited number of studies and models are currently available that assess the performance of water pipelines in Qatar. Therefore, this paper presents a performance/condition assessment model for water pipelines in Qatar. The model considers the three main factors that affect water pipeline performance, namely, physical, environmental, and operational. Questionnaires were distributed among experts in Qatar to determine the weight of the factors affecting the performance of water pipelines in Qatar using Fuzzy Analytic Network Process (FANP). Due to the inherited large uncertainties in the calculated weights, Monte-Carlo acyclic (non-cyclic) simulation was used to include such uncertainty in the development of the performance assessment model. The model was tested using historical data of existing pipelines resulting in an accuracy of 93.6%. Furthermore, the model was used to develop a condition assessment database for water pipelines in Qatar. The model is expected to help municipalities and decision makers to accurately plan for future maintenance and rehabilitation activities of water pipelines' based on their current performance.*

KEYWORDS: *Water Pipelines, Monte-Carlo Acyclic Simulation, Performance/Condition Database.*

❖ INTRODUCTION

In 2003, the National Guide to Sustainable Municipal Infrastructure best practice reported that a planned inspection program must be developed to minimize health and safety hazards for water distribution networks. When they deteriorate over time, water pipelines are subjected to a high risk of failure, which endangers public health, safety, and environment. To reduce such risks, it is necessary to develop a credible condition assessment model for planning inspection and maintenance activities for water pipelines. The condition assessment of water pipelines is usually performed using physical-based and statistical approaches. The direct inspection checks the physical mechanisms of pipeline failures. However, this inspection method requires data, which is either costly or impossible to obtain (Rajani and Kleiner 2001). Thus, physical models can only be justified for major water pipelines due to their large failure cost. On the other hand, statistical methods can be used for all water pipelines because its input data is less costly and easier to obtain.

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The goals of this paper are to: (1) identify the factors affecting the condition of water pipelines, (2) develop a condition assessment model for these pipelines using an integrated FANP/Monte-Carlo acyclic simulation model, and (3) develop a condition assessment database and deterioration curves. The model output is the assessed pipeline condition in a probability distribution form. This will help municipalities and decision makers to make more accurate judgements and to properly plan for future maintenance activities. The model considers uncertainties at initial stages, accumulated uncertainties inherited from the calculation process, and several factors affecting the condition of the pipeline. Three groups of factors that affect water pipeline conditions were identified, namely, physical, environmental, and operational. Questionnaires were distributed among water pipeline experts in Qatar to collect the data needed to develop the model. The Fuzzy Analytical Network Process (FANP) was used to calculate the relative importance weights of the identified factors. Monte-Carlo simulation, which was implemented using Oracle® Crystal Ball software, used the calculated weights as input in the simulation process to yield a probabilistic condition index for water pipelines.

LITERATURE REVIEW

Several studies have been carried out to assess the condition of water pipelines using different techniques. Zhou et al. 2009 developed a condition assessment model for water pipelines using fuzzy PROMETHEE II. Geem et al. 2007 applied multiple linear regression (MLP) and artificial neural network (ANN) techniques to develop a condition assessment model for water pipelines. The results of the study showed the outperformance of ANN technique because of its higher coefficient of determination (R^2). Al-Barqawi and Zayed developed a condition assessment model for water mains based on the Analytic Hierarchy Process (AHP) method (Al-Barqawi and Zayed 2006a) and also based on ANN method (Al-Barqawi and Zayed 2006b). The two methods were combined later to develop a condition assessment model using integrated AHP/ANN (Al-Barqawi and Zayed 2008). Yan and Vairavamoorthy (2003) used fuzzy multi-criteria decision-making (MCDM) technique for water pipeline condition assessment. Geem (2003) used ANN to develop a decision support system (DSS) for water pipeline condition assessment.

The previously developed models for water pipeline condition assessment provided satisfactory results. However, they did not take into account factor interdependency and severity weight uncertainty. The interdependency relationships among influential factors can create dynamics in the form of cause and effect relationships, which can severely affect the pipeline condition assessment. To address the interdependency and uncertainty among factors, FANP and Monte-Carlo simulation were used to generate condition assessments that are more accurate and realistic than those obtained using previously developed models.

Fuzzy Analytic Network Process

Fuzzy Analytic Network Process (FANP) was developed to overcome the limitations of AHP and ANP. AHP does not take into account the interdependencies among the factors used in the assessment process. Although it takes these interdependencies into account, ANP method ignores inherent uncertainties and human judgment during the evaluation of the pairwise comparison of the factors. Converting a verbal pairwise comparison judgment into an exact ratio of how strong an alternative is compared to another includes many uncertainties. Therefore, fuzziness is introduced to ANP to deal with such uncertainties. Many fuzzy pairwise comparison scales are available such as Cheng's scale, Kahraman's scale, Saaty's scale, or a researcher self-defined scale (Etaati et al. 2011). The scale selected in this study is based on Saaty's fuzzifying method, which suggests adding and subtracting "1" from each response of the pairwise comparison in order to obtain the upper and lower matrices, respectively. This means that a response of 5 in the pairwise comparison between two factors P and E will be 4 and 6 in the lower and upper matrices, respectively.

Monte-Carlo Simulation

The development process of condition assessment models for water pipelines in Qatar deals with additional uncertainty generated by the responses provided by engineers and experts. In order to overcome this additional uncertainty, a Monte-Carlo simulation approach is selected to account for and quantify the uncertainty inherited in the model inputs. According to Raychaudhuri (2008), Monte-Carlo simulation relies on repeated random sampling and statistical analysis to compute the results. The usual steps of Monte-Carlo simulation can be summarized in the following steps:

1. Define a domain of possible inputs.

2. Generate inputs randomly from a probability distribution over the domain.

3. Perform a deterministic computation using the generated inputs.

4. Aggregate the results.

METHODOLOGY

The research methodology started by conducting a comprehensive literature review to study the components of water pipeline systems. The literature review was also used to study previously developed condition assessment models, and the techniques used to develop them. A questionnaire was distributed among experts to identify the factors that affect the condition of water pipelines in Qatar. Another questionnaire was also distributed among experts to: (1) perform pairwise comparisons between the main factors and sub-factors affecting the pipeline condition and (2) determine the effect value of each factor on the water pipeline condition. All pairwise comparisons of the gathered responses were subjected to Saaty's fuzzifying scale. Accordingly, the factors' relative importance weights were calculated using the FANP technique. The probability distributions of the obtained factors' weights along with the determined attribute effect values from the different respondents were fitted. They were then used as inputs in the developed condition assessment model using Monte-Carlo acyclic simulation. The model was implemented and tested using actual data from 547 existing water pipelines. Finally, the developed simulation model was used to construct a condition assessment database of water pipelines taking into account all possible combinations of the affecting factor values.

MODEL DEVELOPMENT

The developed condition assessment model is defined by the following equation:

$$OCI_j = \sum_{i=1}^{k} W_i \ x \ EV_i \ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where, OCI_j = overall condition index of water pipeline j; EV_i = effect value of factor i reflecting the factor score; W_i= final weight of importance for factor i; and k = number of factors.

The model yields the overall condition index for assessed water pipelines. The higher the index is, the higher is the pipeline condition. The overall condition index ranges between the values of 0 and 10; which represent the worst and best conditions, respectively. The final weights were calculated using the FANP method. The effect values of each factor also range between the values of 0 to 10, which represents the pipeline worst and best eligibilities, respectively. Even though the effect value ranges are the same as those used for factors, the way to compute them differs. The assessment model was developed using Oracle® Crystal Ball software. Monte-Carlo acyclic simulation was used to randomly generate the input variables and assess the output value. The simulated model was developed using the following five steps:

1. The main factors and sub-factors that affect water pipeline condition were identified and analyzed.

2. The factor final weights (W_i) were obtained from the received questionnaires and their probability distributions were fitted.

3. The factor effect values were determined from the received questionnaires and their probability distributions were also fitted.

4. Equation (1) was used to determine the water pipeline overall condition index (OCI_j).

5. Equation (1) was simulated for several iterations using Monte-Carlo simulation in order to assess the pipeline condition.

DATA COLLECTION

The data collection process was conducted in two main phases. The first phase consisted of identifying the factors that affect water pipeline condition in Qatar. In the second phase, the weight of importance and effect values of the factors identified in the first phase were determined.

Phase (1): Factors Affecting Water Pipeline Condition in Qatar

A comprehensive list of factors affecting water pipeline condition was prepared from literature. The factors were identified and selected from the main list based on their applicability to Qatari water pipeline systems. To check the compatibility of the selected factors, a questionnaire survey was sent to several water main engineers and experts in Qatar. The questionnaire was designed to be open-ended (unstructured) to allow respondents to add factors, which were not originally included. All the respondents agreed that the selected factors were those that affect Qatari water pipelines.

As shown in Figure 1, the selected factors were grouped into three main categories, namely, physical, environmental, and operational. The physical category included pipeline characteristics such as age, material type, size, and installation quality. The environmental category included pipeline characteristics such as ground water level, soil type, and surface type. Finally, the operational category included Hazen-Williams coefficient (C-factor), breakage rate, and water quality.

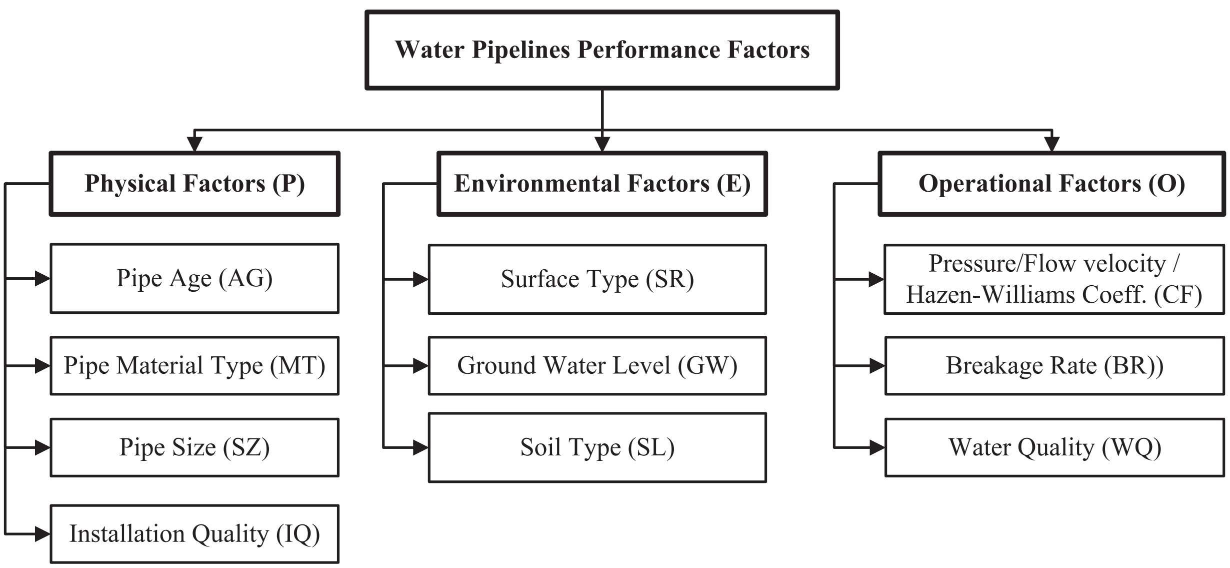

Fig. 1: Factors Affecting Qatar Pipelines' Performance

Phase (2): Factor Weights and Effect Values

A structured questionnaire was designed and distributed among experts in water pipelines and distribution networks. Out of the forty questionnaires distributed, a total of 23 questionnaires were collected, which represents a response rate of 57.5% response rate. Although the response rate can be considered as relatively low, the authors were keen to select experts with ten or more years of experience to ensure as much as possible accurate answers. The questionnaires were distributed to a wide range of water network operators and professionals from different sectors, specifically, material specification engineers, water project design engineers, maintenance engineers, water system analysis engineers, water planning engineers, as well as water project consultants. The questionnaire was mainly used to determine the weight of importance and effect value of each factor on the water pipeline condition. The weight of importance was determined using the results of the pairwise comparisons of the selected factors, which were carried out by Qatari experts.

MODEL IMPLEMENTATION AND TESTING

Based on the number of questionnaires received, 23 different weights were generated for each factor using FANP. As a result, the probability distributions of the obtained weights were fitted. Table 1 summarizes the statistical information for the final weight probability distributions that were selected for each factor. Chi-Squared (Ch-Sq), Anderson-Darling (A-D), and Kolmogorov-Smirnov (K-S) statistical tests were performed to check whether the fitted distributions were statistically sound based on the maximum P-value for the distributions of each factor. The same statistical tests were performed for the effect values of each factor as shown in Table 2. As a result, the two main components required to determine the overall condition index (i.e. weight and effect value) were probabilistic.

The overall condition index was determined by applying Equation (1) for all pipelines under study simultaneously using the developed acyclic simulation model. The model simply runs by multiplying each pipeline's probabilistic effect value for each factor by the probabilistic final weight of the corresponding factor. The results of these multiplications are then added up to determine the mean overall condition index for each pipeline. This process is repeated for 1,000 iterations (simulations). The stopping criterion parameters were set equal to 5% accuracy ($\varepsilon = 0.05$) with 99% confidence ($\alpha = 0.01$). In each Monte-Carlo simulation iteration, a random final weight and effect value were chosen based on their individual probability distributions. This randomness ensures that uncertainty is considered and the mean value of the overall condition index (OCI_j) obtained is the final condition value for each pipeline. Finally, based on the condition value, the operator can decide which actions can be taken for the pipeline, which is outside the scope of this study.

The model was tested using a historical data of 547 existing water pipelines. The simulation model was used to determine the mean predicted overall condition index for each pipeline. Figure 2 shows a sample of one of the pipeline probabilistic predicted condition index. The model's predicted pipeline conditions had an accuracy of 93.6% when compared with actual conditions.

Table 1: Summary of Statistical Analysis Results for Factors' Weights

Main Factor	Sub-Factor	Distribution	Mean Final Weight (μ)	Standard Deviation (σ)	Variance (σ^2)	Standard Error (ε)
PHYSICAL	AG	Lognormal	0.082	0.08	0.010	0.02
	MT	Exponential	0.095	0.06	0.002	0.01
	SZ	Exponential	0.096	0.09	0.010	0.02
	IQ	Min.Extreme	0.109	0.07	0.010	0.01
ENVIRONMENTAL	SR	Lognormal	0.071	0.09	0.010	0.02
	GW	Gamma	0.137	0.08	0.010	0.02
	SL	Exponential	0.130	0.10	0.010	0.02
OPERATIONAL	CF	Exponential	0.081	0.09	0.010	0.02
	BR	Lognormal	0.098	0.09	0.010	0.02
	WQ	Lognormal	0.102	0.07	0.010	0.01

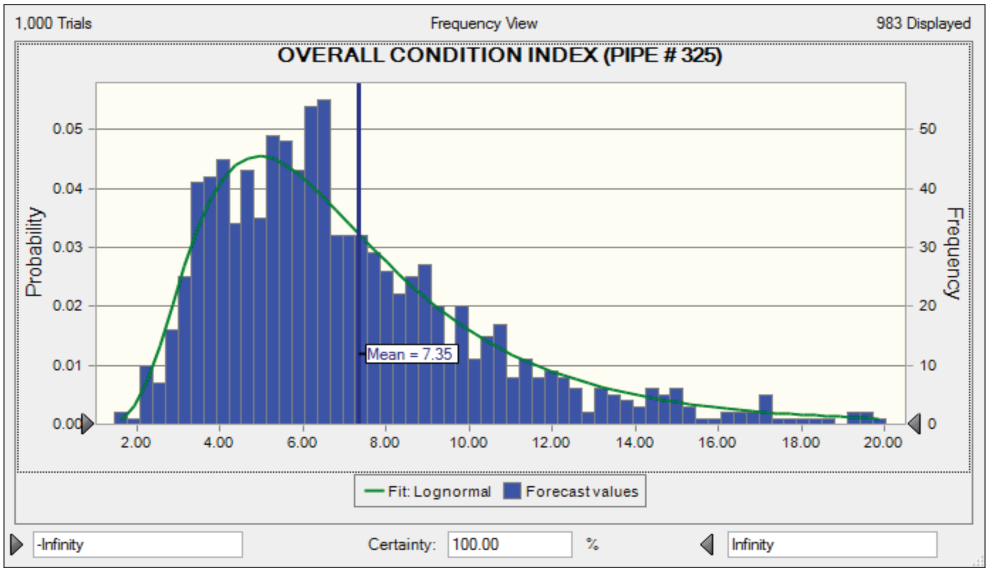

Fig. 2: Overall Condition Index Probability Distribution for Pipeline No. 325

Table 2: Summary of Statistical Analysis Results for Factors' Effect Values

Factor	Characteristic	Distribution	Mean Effect Value (μ)	Standard Deviation (σ)	Variance (σ^2)	Standard Error (ε)
AG	Old (> 70 years)	Normal	1.24	1.300	1.690	0.28
	Medium (30 – 70 years)	Uniform	4.81	1.401	1.962	0.01
	New (< 30 years)	Max. Extreme	9.52	0.602	0.362	0.13
MT	Asbestos	Normal	5.52	0.981	0.962	0.21
	Cast Iron	Uniform	5.62	0.921	0.848	0.20
	Concrete	Max. Extreme	6.62	0.865	0.748	0.19
	Ductile Iron	Uniform	7.62	1.024	1.048	0.22
	PVC	Lognormal	9.52	0.750	0.562	0.16
SZ	Small (< 200 mm)	Gamma	3.10	1.546	2.390	0.34
	Medium (200 – 350 mm)	Normal	6.48	1.365	1.862	0.30
	Large (> 350 mm)	Max. Extreme	9.67	0.658	0.433	0.14
IQ	Poor	Normal	2.52	1.692	2.862	0.37
	Fair	Uniform	5.81	1.504	2.262	0.33
	Good	Max. Extreme	9.52	0.750	0.562	0.16
SR	Asphalt	Uniform	4.57	2.619	6.857	0.47
	Seal	Normal	6.29	2.493	6.214	0.44
	Foot Path	Normal	7.24	2.211	4.890	0.48
	Unpaved	Normal	7.57	2.293	5.257	0.50
GW	Shallow	Max. Extreme	2.24	1.814	3.290	0.40
	Moderate	Uniform	5.67	1.528	2.333	0.33

	Deep	Beta	9.57	0.598	0.357	0.13
SL	Aggressive	Logistic	1.67	1.826	3.333	0.30
	Moderate	Gamma	5.00	1.304	1.700	0.28
	Non-Aggressive	Max. Extreme	9.86	0.359	0.129	0.08
CF	Low (< 41)	Pareto	3.43	1.469	2.157	0.32
	Medium (41 – 101)	Uniform	6.24	1.578	2.490	0.34
	High (> 101)	Max. Extreme	9.90	0.301	0.090	0.07
BR	High (> 0.5 breaks/km/yr)	Logistic	1.62	1.465	2.148	0.32
	Medium (0.1 – 0.5 breaks/km/yr)	Normal	4.62	1.322	1.748	0.29
	Low (< 0.1 breaks/km/yr)	Max. Extreme	9.95	0.218	0.048	0.05
WQ	Poor (High Impurities Level)	Normal	2.10	1.578	2.490	0.34
	Fair (Medium Impurities Level)	Normal	5.14	1.315	1.729	0.29
	Good (Low Impurities Level)	Max. Extreme	9.90	0.301	0.090	0.07

CONDITION ASSESSMENT DATABASE

In order to facilitate the use of the developed acyclic simulation model, a Matlab program was developed to generate all possible combinations of the identified factors and their corresponding characteristics. As shown in Table 2, each factor has three or more possible characteristic. For example, the "size" factor has three characteristics (i.e. small, medium, and large). Multiplying the number of factor characteristics by each other will generate a total number of 131,220 combinations. However, the material type, which is used in Qatari water pipelines, is ductile iron. As a result, the "material type" factor has only one characteristic (i.e., ductile iron). Thus, the final generated database has 26,244 different combinations. Consequently, the developed simulation model was applied on the generated database to determine the predicted overall condition index for each combination. Such database can be useful to facilitate the determination of the overall condition index for a given pipeline as soon as its characteristics are known. A sample of the database is shown in Table 3. For instance, let us consider a 40 year old ductile iron water pipeline with a 150 mm diameter. The pipeline is also assumed to have a high quality of installation and is located under asphalt with a very close ground water level. Moreover, the pipeline's surrounding soil type is aggressive and it carries water with medium level of impurities. Finally, the C-factor and breakage rate of this pipeline are assumed equal to 120 and 0.8, respectively. Based on these assumptions and with the help of Table 2, the linguistic characteristics of this pipeline will be: medium, ductile iron, small, good, asphalt, shallow, aggressive, high, high, and fair for the factors of age, material type, size, installation quality, surface type, ground water level, soil type, C-factor, breakage rate, and water quality, respectively. Using Table 3, the case that matches the pipeline characteristics is case number 8750 which predicts a condition index of "5.6".

The constructed condition assessment database can be also used to develop different deterioration curves for the water pipelines based on different pre-defined combinations of the factors. Practically, the factors of size (SZ), installation quality (IQ), surface type (ST), ground water level (GW), and soil type (SL) are considered constant throughout a pipeline's lifetime. Thus, the changing factors with respect to age will be the C-factor (CF), breakage rate (BR), and water quality (WQ). Figure 3 shows integrated deterioration curves for three pipeline sizes (i.e. small, medium, and large) based on the previous assumptions. The curves were plotted in three sectors. The first sector (from installation to year 30) was plotted assuming the best characteristic combinations for the IQ, ST, GW, and SL factors. The second sector (from year 31 to 70) was plotted assuming moderate characteristic combinations for the IQ, ST, GW, and SL factors. Finally, the third sector (from year 71 to 100) was plotted assuming the worst characteristic combinations for the IQ, ST, GW, and SL factors. For the three sectors, the CF, BR, and WQ factors were changed reasonably with respect to age. It is clear from the figure, that large size pipelines have better conditions throughout their lifetime than smaller size ones. Usually, smaller diameter pipelines have a higher probability of failure than larger ones because possible smaller standard dimension ratio (SDR) affects the structural performance of a pipeline and makes it more vulnerable to external impact or third party damage. In addition, smaller diameters have thinner wall thickness which allows faster corrosion rate.

Alternatively, individual water pipeline deterioration curves can be also developed from the constructed database by alternating the possible characteristics of the IQ, SR, GW, and SL factors throughout the pipeline estimated lifetime. 108 different deterioration curves can be developed representing all the possible cases based on the previous assumptions. Figure 4 shows a sample deterioration curves when IQ is “good”, SR is “unpaved”, GW is “moderate”, and SL is “moderate”. It is worth mentioning that the deterioration curves shown in both Figures 3 and 4 does not take into consideration any type of repair, rehabilitation, or maintenance actions that usually takes place.

CONCLUSIONS

This paper presents a condition assessment methodology for water pipelines in Qatar considering uncertainties and interdependencies among factors and sub-factors. A total of ten factors were identified to affect the condition of water pipelines. These factors were divided into three main categories, namely, physical, environmental, and operational. The importance weights of these factors were calculated using FANP technique which considered the inner interdependencies between factors. An integrated acyclic simulation/FANP model was developed to assess the condition of water pipelines in Qatar. This integration provides three main benefits: (1) make decisions under uncertainty, (2) encompass interdependencies among criteria, and (3) handle decisions that involve large number of variables. The model was tested using the data of 547 existing water pipelines with an accuracy of 93.6% indicating a satisfactory model performance. Finally, the developed model was used to develop a database containing a total of 26,244 different cases that were generated by considering all possible combinations of factor characteristics. The database was used to develop different deterioration curves. The model is expected to help municipalities and decision makers to accurately judge and plan for future water pipeline maintenance and rehabilitation activities based on their current condition as it takes into consideration both, the uncertainties at initial stages and the accumulated uncertainties inherited from the calculation process.

ACKNOWLEDGEMENT

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Table 3: Sample of Condition Assessment Database

Case #	Age	Material Type	Size	Installation Quality	Surface Type	Ground Water Level	Soil Type	C-Factor	Breakage Rate	Water Quality	Condition Index
55	Old	Ductile Iron	Small	Good	Foot Path	Shallow	Aggressive	High	High	Poor	5.1
56	Old	Ductile Iron	Small	Good	Foot Path	Shallow	Aggressive	High	High	Fair	5.4
4333	Old	Ductile Iron	Medium	Fair	Asphalt	Moderate	Moderate	Medium	Medium	Poor	5.2
4334	Old	Ductile Iron	Medium	Fair	Asphalt	Moderate	Moderate	Medium	Medium	Fair	5.5
4335	Old	Ductile Iron	Medium	Fair	Asphalt	Moderate	Moderate	Medium	Medium	Good	6.0
8693	Old	Ductile Iron	Large	Poor	Seal	Deep	Non-Aggressive	Low	Low	Fair	6.9
8694	Old	Ductile Iron	Large	Poor	Seal	Deep	Non-Aggressive	Low	Low	Good	7.4
8749	Medium	Ductile Iron	Small	Good	Asphalt	Shallow	Aggressive	High	High	Poor	5.3
8750	Medium	Ductile Iron	Small	Good	Asphalt	Shallow	Aggressive	High	High	Fair	5.6
13135	Medium	Ductile Iron	Medium	Fair	Foot Path	Moderate	Moderate	Medium	Medium	Poor	5.7
13136	Medium	Ductile Iron	Medium	Fair	Foot Path	Moderate	Moderate	Medium	Medium	Fair	6.0
13137	Medium	Ductile Iron	Medium	Fair	Foot Path	Moderate	Moderate	Medium	Medium	Good	6.5
17441	Medium	Ductile Iron	Large	Poor	Seal	Deep	Non-Aggressive	Low	Low	Fair	7.3
17442	Medium	Ductile Iron	Large	Poor	Seal	Deep	Non-Aggressive	Low	Low	Good	7.7
17497	New	Ductile Iron	Small	Good	Asphalt	Shallow	Aggressive	High	High	Poor	5.8
17498	New	Ductile Iron	Small	Good	Asphalt	Shallow	Aggressive	High	High	Fair	6.0
21883	New	Ductile Iron	Medium	Fair	Foot Path	Moderate	Moderate	Medium	Medium	Poor	6.2
21884	New	Ductile Iron	Medium	Fair	Foot Path	Moderate	Moderate	Medium	Medium	Fair	6.5
21885	New	Ductile Iron	Medium	Fair	Foot Path	Moderate	Moderate	Medium	Medium	Good	6.9
26189	New	Ductile Iron	Large	Poor	Seal	Deep	Non-Aggressive	Low	Low	Fair	7.7
26190	New	Ductile Iron	Large	Poor	Seal	Deep	Non-Aggressive	Low	Low	Good	8.2

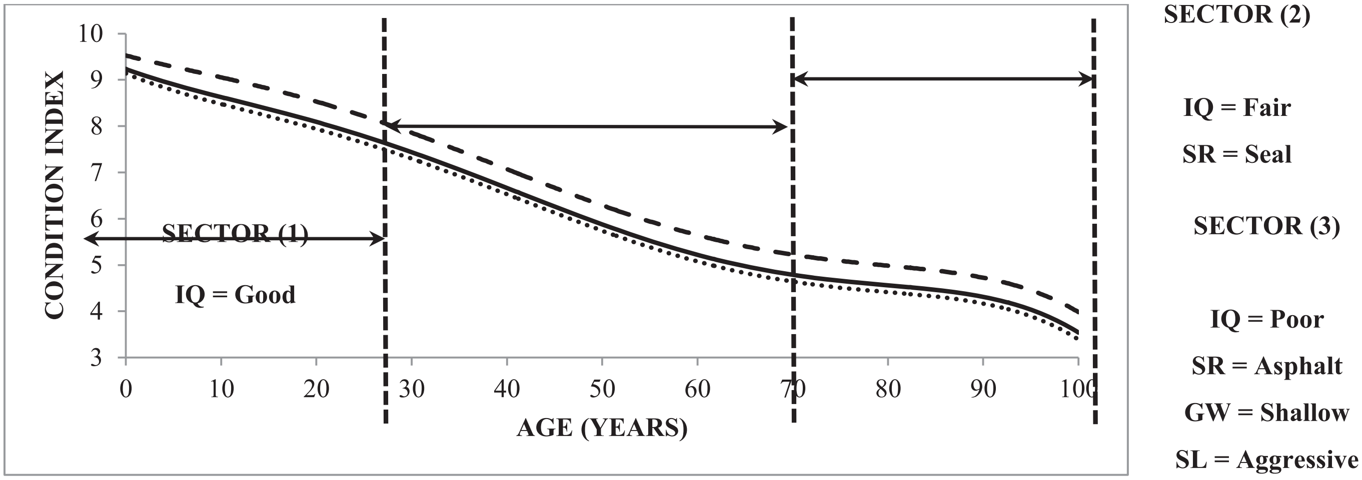

Fig. 3: Integrated Deterioration Curves

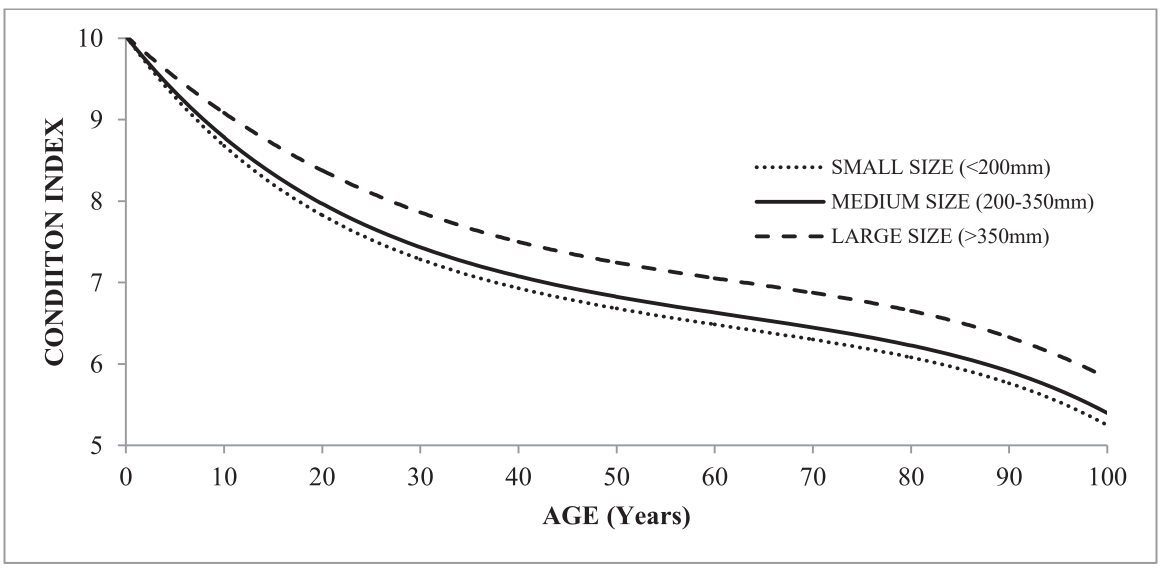

Fig 4: Deterioration Curves Sample (IQ = Good, SR = Unpaved, GW = Moderate, SL = Moderate)

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VISUALISING URBAN ENERGY USE: The potential value of remote sensing & LiDAR data in urban design and energy planning[1]

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ABSTRACT: *LiDAR (light detection and ranging) is an optical remote-sensing technique that uses laser light to densely sample surfaces, producing highly accurate measurements. It is primarily used in airborne laser mapping applications. However it offers a huge potential for improving the data input available for modelling urban energy systems and visualising urban carbon emissions. This paper explores this potential and highlights some of the limitations of the information that can be obtained from LiDAR data and how these limitations can be ameliorated. To do so it presents an example of the use of LiDAR data and aerial imagery to provide input data for building geometry and building physics models to develop an energy model of a mixed-use inner urban area in the North East of England.*

The work presented highlights the significance of data accuracy for the assessment of heat-loss parameters, orientation, shading and renewable energy micro-generation; and the limitations of remotely sensed data and how these can be ameliorated using a combination of open-source property data, such as building age, occupancy, tenure and existing stakeholder data sets, including building services and measured energy performance.

The paper concludes that there are significant benefits in the use of LiDAR data for improved accuracy in, and visualization of, urban energy use and carbon emission calculations. However it also highlights that further work is required to reduce the data manipulation required if the potential of Lidar data is to be fully exploited to inform urban energy modeling.

KEYWORDS: *Remote sensing, LiDAR, energy modeling, urban planning.*

❖ INTRODUCTION

There is a challenge of managing urban change within the paradigm of the ‘information city’ (Kraemer & King 1988). Municipalities and their partners require a supporting information infrastructure that helps a broad range of urban stakeholders to both understand and reinforce geophysical communities within urban neighbourhoods and localities (Doheny-Farina 1996). The city map and urban model remain the most intuitive ways of structuring and accessing this urban information.

“The ability to routinely access the infinity of global archives of own and other experience provides a tool for exploring own identity and for better understanding … through virtual technologies … technology can be used to reconstitute as well as to fragment” (p10 Little et al 2000).

In this changing environment, issues of sustainability and energy efficiency are among the most significant challenges of urban planning with regard to accessing, mapping and visualising digital data. Typically energy use in buildings is around half of all energy consumed and it clearly has a strong spatial component that relates to individual buildings, neighbourhoods, districts and ultimately municipalities. It is within this context that the value of remotely sensed data and its role as part of the city’s strategic information infrastructure has been examined in the research presented.

Appropriate and accurate data is crucial to understanding the viability of both substantive urban systems and the decision-making procedural systems that manage the urban system (Grossmann & Watt 1992). In effect there are complementary requirements from both technical and non-expert urban stakeholders in the use of urban energy information, its collection, analysis, sharing and visualisation. Here there is real potential for LiDAR data; collected remotely at the neighbourhood or city scale; to simultaneous contribute to both the technical and political

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decision-making requirements for better data.

Initially LiDAR is ideal for information directly relating to building geometry. This geometry or 'property-based' data can be the basis for integration with data related to the wider and 'softer' aspects of urban planning and sustainability.

Early European Commission funded work found that "... remote sensing (is) technically suited to the collection of information needed for certain types of area planning ... that require systematic collection of certain statistical information" (p31 Cardoso 1996). In this context, it should clearly include energy and emissions planning. Yet, to date, there has been little practical use made of remotely sensed data at the scale of individual buildings and their levels of energy efficiency and carbon emissions.

There have been a few research-specific applications of remotely sensed data addressing the challenge of understanding the energy performance characteristics of a large building stock, using city-wide data sets and simplified calculation processes. For example, a recent demonstration project based in Milan involved the development of a GIS based city buildings database (Caputo et al 2013) and a Toronto case study used LiDAR data sets as input data for building energy calculation (Tooke et al 2014). In addition, there have been specific use of LiDAR to understand the potential for the application of large scale solar PV panels (For example see Borfecchia et al 2014, Jacques et al 2014) using assumptions around roof space of different property typologies. However, many of these current approaches are concerned with assumed input data from a LiDAR survey for existing commercial energy calculation software, albeit data that is based upon limited number of sampled properties and the use of building archetypes. In most cases of modelling the energy performance of the existing building stock, there is an emphasis on a simplified calculation process using the best data available given the costs of collection and calculation - what can be described as the 'Best Available Data Not Entailing Excessive Costs'. While these methods are generally pragmatic and appropriate to the level of decision-making relating to local policy making and / or capital investment into building improvements, the results are an estimate, where the accuracy of the estimate is largely dependent upon the quality of the data used. Underlying each method and application is the quality of the input survey data used in the calculation process.

This paper suggests that the real benefit in pursuing a simplified calculation process using semi-automated data sets, such as LiDAR scanning, is the ability to make better strategic decisions on the existing building stock. For example, in this project researchers assumed the adaptation of a standardised data collection process (RdSAP) that has certain requirements for necessary input data. In such a simplified method of energy calculation, the data quality and accuracy has to be fit for purpose, rather than over specified. Practical pragmatism has to balance the complexity of the model against the quality and availability of the urban data sets.

Recently this has been recognised in project work looking at the development of a theoretical framework for energy modelling at the urban scale (Keirstead et al 2012) that could be supported by appropriate big data sets and cloud computing. This research suggested the potential development of new models or the successful integration of one or more existing models (mix of geometry, building uses / activities, transportation etc.) and the potential of LiDAR data extraction for specific building elements such as facades details (Kan and Sun 2014) in addition to building geometry. Yet recent research also contains a common acknowledgement of the intrinsic difficulties of acquiring good quality data, and of integration different models at the right resolution (Kedzierski and Fryskowska 2014) to make this practicable.

This limited use of remotely sensed data to fill such a gap in requirements for good quality data is despite the importance of the collective level of carbon emissions from the domestic property sector, where estimates are often at best a mix of modelled usage. This modelled use of energy efficiency has a common acceptance of the use of the property assessed independently from the variations of occupancy (Boardman et al 2005) and grounded in the basic attributes and parameters of the building. Hence it is possible to generate an estimation of an individual property energy use based on the attributes of the building (age / method of construction, geometry and services) and 'standardised' behaviour of the typical occupants. It is these property attributes that are well suited to the integration of LiDAR data on geometry with other open-source and publicly available data sets that record the building performance characteristics. For example, the use of open source database on the age of construction of the property, the use of stakeholders' own asset management database, systems upgrades to social housing as part of decent homes programme.

As part of an EU 7th Framework funded research project, the potential of a variety of publicly accessible and open-source data sets were explored through a series of European case studies. These case studies identified data that can be edited, integrated and visualised to support energy efficiency within urban design and planning. The focus of one of these case studies was on identifying the refurbishment options for an inner-city residential area in Newcastle upon Tyne in the UK. The study area contains different housing typologies, including single family properties and multi-story and multi-occupancy properties. A lack of accessible and affordable property data available for the area led to the commissioning a LiDAR survey, primarily to provide accurate building heights.

The remainder of the paper explores the collection, editing and use of this LiDAR data, its potential application and the practical limitations. This is presented as a series of discussions that follow the sequential steps needed from specification of the survey through to data integration tasks within an urban energy model. It concludes with a discussion around the potential value that LiDAR data can provide and some of the key issues that need to be resolved in order to fulfil this potential.

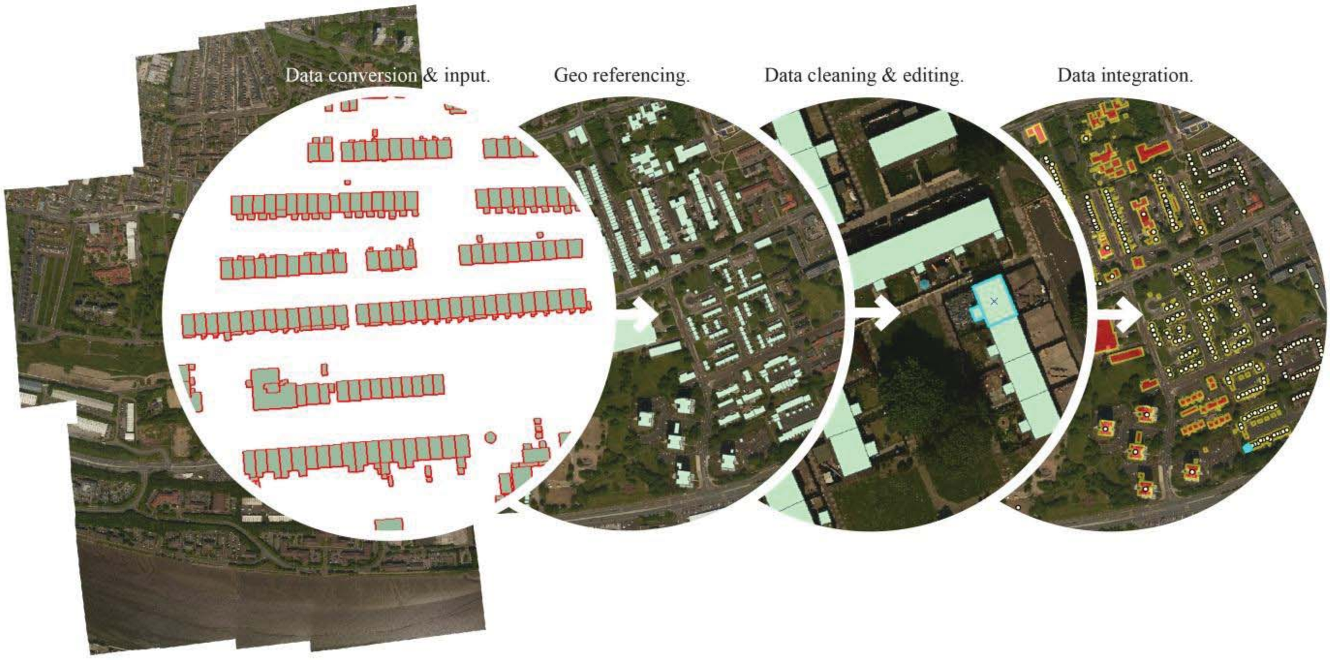


Fig 1: Key steps in data handling.

Building geometry data and user-defined mapping

LiDAR data was required to provide accurate measurements of building geometry to inform the estimation and modelling of urban energy systems. The commissioned LiDAR data also had the advantage that it includes the copyright required to allow its integration with other data sets as part of an online energy modelling and decision-support tool (Madrazo et al 2013). The rights to share this data and demonstrate the potential functionality when combined with other data sets was also a key advantage. This allowed an open-ended approach to the use and adaptation of the data set without time-limitations or legal restrictions on its use.

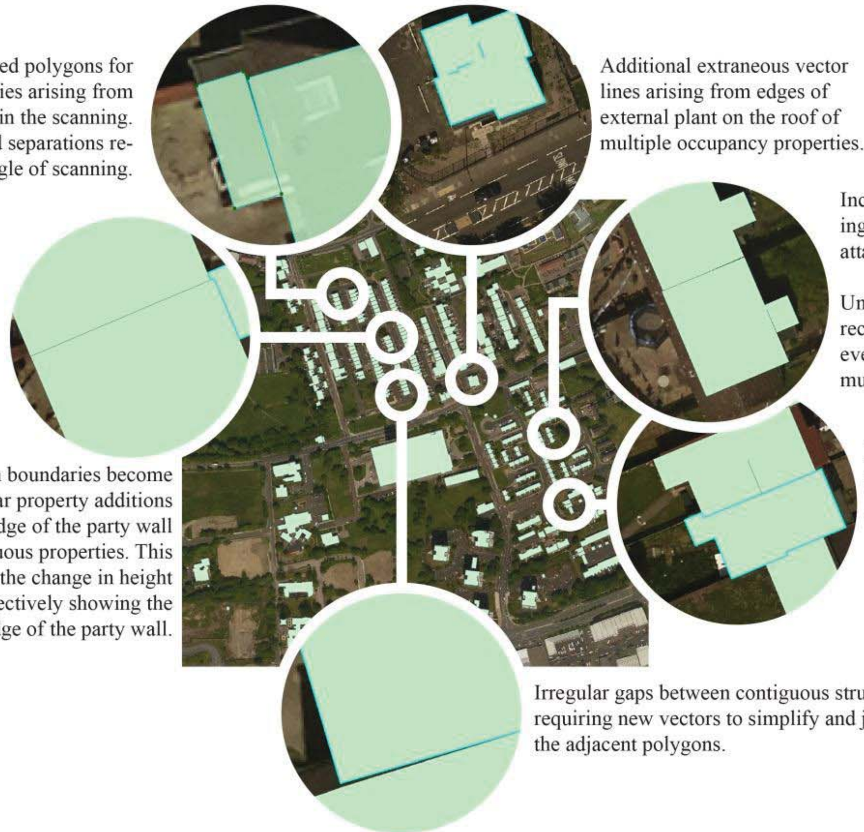
DATA SPECIFICATION & COLLECTION

A commercial provider (BlueSky) conducted the LiDAR Survey and supplied the LiDAR Data. In retrospect, much was learnt regarding the specification of the data collection processes. Most significantly there is the lack of any standard specification for the format, resolution and cleaning of the data. It became clear in the case study that the end-use or application of the data should have informed the format of data from LiDAR survey in the tender from the outset.

Data conversion & input

The data was provided in CityGML and Collada formats that are readable within many different standard software packages. Over a square kilometre of the inner city was surveyed with two separate scans that provided a terrain model and 'partially' auto-rectified structures.

Typically LiDAR has over specification of details in certain areas and significant gaps regarding surface materials and varied dimensions of solid / opaque surfaces. There are some recent demonstrations of the application around the detail available and transferring or 'tracing' (Kimpton et al 2010) CAD polylines over a polygon surface model / point cloud data. This is effectively a manual task to reduce the level of detail within the model. It turned a set of point cloud data into closed polygons – polygons with properties suitable for adding attributes and for visualisation.



A similar approach was required at the neighbourhood scale to make the data usable for the purposes of estimating the energy use of individual properties.

Fig 2: Highlighting the initial LiDAR data errors.

Ultimately the data had two significant geometry values that needed to be maintained as input measurements into a reduced data standard assessment procedure (RdSAP) or estimated SAP calculation process as the normal UK energy model. This input geometry is (a) the shape of the property; measured as the gross external footprint of the individual dwelling unit; and (b) the height of the property. Together these two input parameters allow an accurate calculation of heat-loss parameters around the extent of internal heated living space relative to the exposed surface areas as made up from the ground floor, external walls and roof. While there are limited opportunities for changing the shape (simplifying) and size (reducing) of homes to affect the heat loss parameters (Friedman 2005), building fabric interventions (typically internal or external insulation) can improve the thermal efficiency of specific building elements to reduce the heat loss. In most cases, improvement work to the building fabric will also be dependent upon the same geometry in terms of cost of treatment per square metre. Further interventions relate to possible upgrades to building services or the provision and connection to renewable and / or decentralised energy systems. These can also be attached as attributes to the property-based data. Consistent with similar scoping and qualitative assessments of stakeholder requirements (National Refurbishment Centre 2012) and those responsible for property management and maintenance, there is a practical focus on cost-effective and technically trusted approaches to refurbishment that requires good evidence based on accurate data.

To obtain accurate building geometry data it was necessary to identify any significant errors inherent in the original format of the commercially provided data and undertake some data editing.

Errors within data collection

There were several kinds of errors arising from the initial data collection (fig. 2) that had to be addressed in advance of having useful data sets for energy modelling. These are almost exclusively issues of 'bad geometry' arising from a combination of the angle of scanning of the terrain and properties together with the level of 'noise' within the LiDAR data. The 'noise' included errors from building overhangs, shadows, trees / vegetation and became more pronounced in areas where there were more complex geometries and structures.

The best strategy for dealing with the mix of geometry errors was to create two separate data sets that held discrete input data. The first dealt with building footprints and the second with building heights.

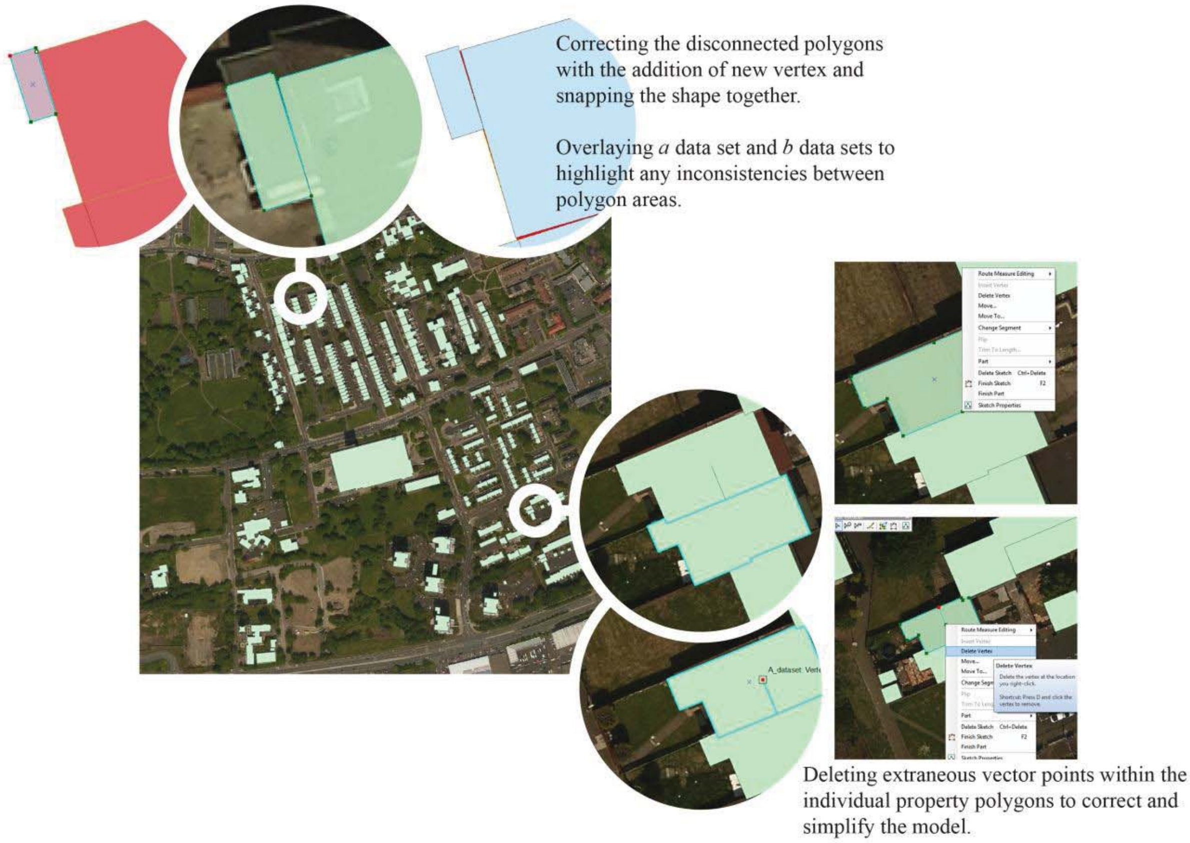


Fig 3: Examples of correction of data errors.

Data cleaning and editing

In advance of this, the basic errors in the data had to be cleaned up as the first step in data handling. Editing was undertaken using the edit functions within ESRI's ArcGIS (fig. 3).

Overlapping polygons in the commercial data set were clear errors as they represented two properties occupying the same building footprint. These were merged and then split along an estimated property boundary. Disconnected polygons or 'gaps' in between terrace properties were similarly impossible structures. These had their vertices snapped to match.

There were several instances of vertices existing within polygons that seemingly picked up variations in roof structures, chimneys / ventilation or in some instances of larger multi-occupancy properties and non-residential units mechanical and engineering services plant on the roof. These were merged into single polygons with all extraneous vertices deleted. The result was (a) data set that held accurate footprint data.

Identifying individual properties

The next step was to separate the contiguous polygons / structures into individual properties. It was helpful that the LiDAR data was effective in picking up changes in external building heights. In an area of exaggerated topography in the west end of Newcastle where contiguous properties / terraced housing step up and down the slope, this suggests division between properties. However in looking in detail, it failed to make a distinction between property boundaries because this boundary is in reality the thickness of a party wall between the individual properties. The change in roof heights coincided with the end (or in some instances the roof overlap) of the party wall and not the middle of the party wall. This becomes more evident when rear extensions have to be attributed to a particular property polygon. This could only be corrected manually using 'best-guess' information (Fig. 4) based on equidistant polygons to create properties of equal sizes as a typical property typology or using external clues to property boundaries.

Fig 4: Data editing to create individual property polygons.

There had to be an acceptance that additional errors were introduced at each of these discrete stages in data cleaning and editing. Maintaining two separate data sets holding the footprint and height details separately was the best strategy to reduce the number of stages in data handling and thus reduce the potential to introduce any new errors from data handling.

INTEGRATION WITH OTHER DATA SETS

Thinking around the value of city models is rapidly changing in response to the power of computing but more significantly, the quantum of big data that now exists digitally.

Planning practitioners are entering into a world where everything is data. Planning has to deal with the scope of different sources of supporting evidence each using a variety of methodologies. There has to be an understanding of limits, unpredictability and allied to this are the procedural issues around irrationality, objectivity and political / cultural perceptions and definitions of qualitative aspects of behaviour, knowledge, attitudes and perceptions. Maps are clearly a useful way to explore data. But ultimately they are didactic tools. They are abstractions of reality and designed primarily for exploration and understanding at strategic scales and early stages of decision making. They will contain errors and have to be treated as tools for understanding rather than predicting energy usage.

Planning practitioners are currently experiencing the development of the 'map' or 'model' from physical to digital, a paradigm shift in urban design and planning "… that hold(s) the potential for allowing the designer to move directly from concept to full scale construction" (p8 Porter & Neale 2000). In order to achieve this, there has to be the development of new methodologies to support the analysis and integration of large data sets (Aiden & Jean-Baptiste 2013). Real 'big data' can be considered a replacement for intuition or guesswork where there are strategies in place for harvesting and mining every possible source (Baumgartner et al 2012).

Stakeholder data and user-defined mapping

Big data tends to be messy data. One of the key support tasks is to organise, structure and make sense of this big mess. This is generally done using one or more of the industry standard software packages, ArcGIS, AutoCAD / Revit, Sketchup and to a lesser degree, GoogleEarth. There is also open-source mapping software and data, for example in the ESRI sponsored crowd-sourced mapping (Medeiros 2013). Building energy data is just another element of this big data. Building energy use and carbon emissions have to be understood in the wider policy context and the complexity of the real world. We have to provide the ability for users to export, import and connect with their own datasets to build on the functionality of the basic building geometry.

The significance of remotely sensed data is that it provides accurate building geometry. This geometry has value as input data for the calculation of the energy efficiency of buildings. When shared online it also has a range of additional functionality where other data can be linked to the individual property address or when there is a requirement for accurate measurement. For example, in the calculation of property refurbishment and renovation costs where building geometry is linked to a cost database or cost estimations.

Fig 5: Data compared to Google Earth.

The availability of open-source three-dimensional data is both limited and controlled. The impressive representation of the same case study area of Newcastle in Google Earth effectively uses the same data from the same commercial supplier (fig. 5). Yet the functionality of this is limited to basic visualisation and the virtual exploration of the urban environment. Any export functions are limited to two dimension aerial imagery, creating a level of frustration in the level of accuracy available through open-source data compared to the knowledge of the existence of accurate geometry. Yet this data is still currently just a collection of shapes without property specific tagging. Beyond the visualisation of the data are extractable geometry models that can be used for a variety of purposes, including acting as input data for more detailed urban design and architectural modelling.

Although it is a significant way short of BIM standards, this is potentially the next step in the use of open source LiDAR information. Format and specifications in line with emerging standard BIM protocols, such as Cobie, and which can be useful at the earliest stages of a design or construction plan of works. At present ISO 1006-2 sets the specification standards for ICT in construction projects and includes a detailed ontology for construction and building elements. This standard also sets out the design responsibilities between different professional stakeholders and the minimum requirements for technical / digital information change between the professionals. The standard has overlaps with Cobie standards for data exchange which sets out the specification of element properties in the form of an industry standard data language with specification properties.

As an increasing range of software packages use Cobie standards for data input and integration, the challenge is to allow the use of remotely sensed LiDAR data on building geometry to be useful and time-saving as input data into these design software packages. Here the best versions are mostly automated from Revit or similar Solibri compliance checking software. When remotely sensed data can be used with confidence at an early project stage and form part of the initial information exchange it will have significant new functionality. It has to be remembered that while most design packages and protocols are intended for new construction, around 80% of all construction projects still include existing structures for renovation, refurbishment, adaptation or conversion (Itard & Meijer 2009). An accurate representation of existing structures with a usable database containing the attributes and parameters of these structures will be a hugely valuable addition to the initial business planning stages of many urban planning and regeneration projects.

THE IMPORTANCE OF VISUALISING ENERGY DATA

"To an architect, a plan is a drawing; to a planner it is a written document. From such small but vital distinctions, the two professional have grown apart dramatically … however, incursions by architects into the field of planning … are returning to its roots in physical design" (p19 Walters 2007).

Lessons from practitioner reflection (Schön 1982) suggest that learnt experience is actually limited by the view of the role and function the planner has of themselves – in effect of 'title (or job description) dictating behaviour'. Stakeholders acknowledged that too much evaluation of successful urbanism is based on quantitative measurements, and often aggregated measures that fail to understand aspects of scale on design quality. Yet they also accepted the need for 'smart measurement' to increase the understanding of the site or project in the appropriate context. Urban planning and regeneration is complex. It brings together a broad range of stakeholders, as a mix of technical professionals and many different non-expert stakeholders that have their own personal and organisational experiences. Urban planning and management has become a two-way educational mutual learning process (Wals 1996) that have connections between many consultation / participation exercises.

These urban planning processes require the development of an evidence base and information provision that is interoperable, exchangeable, accessible and understandable to the broad scope of project stakeholders. Indeed, Castells (2000) suggested that that the appropriate sharing of urban data assists with the reform and legitimisation of local democracy and governance. Data, including energy data, with all of its errors is best shared in a manner that is accessible to multiple stakeholders. It should be understandable to non-technical users, but also extractable and editable for technical users. It is in this planning context that the research project is currently testing the functionality of the edited LiDAR data sets through an on-line platform that allows the full range of stakeholders to use the data (Fig. 6).

Fig 6: Screen shots of the online Semanco platform. Selection of properties within a suitable range for the SAP (estimated property energy efficiency) and the potential improvements following changes to the building fabric.

This is still work in progress and subject to continual review regarding the visualisation of the date, the design of the interface and usability of a number of decision support tools. The intention is that this interface is designed to aid intuitive understanding. There are well-established examples of graphic representation of mapping (Tufte 1983) and visualisation being the manner in which complex data is accessible. As the on-line platform is explained and demonstrated to stakeholders outside of the initial case studies, the importance of the visual three-dimensional interface as a common language (Madrazo et al 2013, 2014) for a range of stakeholders becomes more apparent.

CONCLUSION

The research shows that there are clear potential significant benefits in the use of LiDAR data for improving the accuracy of input data into urban energy models. However, this potential benefit is matched by a clear need for more accurate data relating to existing building geometry within even the most simplified building energy models. Accurate geo-referenced building footprints, heights, roof areas and orientation are a critical starting point for integration with other performance attributes of the building relating to the fabric, systems and occupancy. When these input measurements improve, the standardised energy estimations also improve.

Yet at present the regular application of LiDAR or remotely sensed data for district or city-scale energy modelling is limited. It is likely to remain so until the mixed issues of data quality and translational errors can be resolved. As discussed, these errors are a combination of data collection / data editing errors that have tended to become exacerbated with issues of interoperability between software packages, platforms and human errors.

Yet a better understanding of the end-use application of the data that is typically beyond the visualisation of the physical building form would help in addressing some of these limitations. At the collection stage, the survey specification has to be informed by the end-use of the data as it relates to the level of resolution in the scanning reflecting the urban or building scale being modelled. At the editing and processing stages there are aspects of simplification that would go a long way to improve the accuracy and associated functionality of the data.

Processing can be improved by informed assumptions about the geometry of real-world buildings and structures, for example in understanding the nature of contiguous properties and correcting unrealistic gaps between buildings and impossible overlaps of different structures. If these assumptions can be automated as part of the initial data conversion and auto-rectification stages it would allow for large scale use of LiDAR without significant additional time or cost and hence make the use of the data attractive for energy modelling.
It could be argued that many of the simplified building energy calculation processes used throughout the European Union are defined around the availability and cost of acquiring meaningful input data. As the availability of more accurate data on the geometry of existing buildings increases, it is likely that it can be matched with better input data for building characteristics. This in turn will help to make better energy calculations and predictions, guide better investment decisions through better visualisation of the energy efficiency at a variety of different scales of operation.

ACKNOWLEDGMENTS

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DYNAMIC WEB3D VISUALISATION OF OIL & GAS FACILITY ASSETS[1]

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ABSTRACT: *Efficient information management in the oil and gas industry is crucial to provide all of the data flows, required to support the business and safe operation of facilities. The cost of creating digital facility asset data sets increases, if it is performed late in the delivery process, as it becomes increasingly difficult and expensive to retrieve missing information. There is a need to develop approaches and tools for the management of such data sets throughout the whole project lifecycle. This includes the harvesting of heterogeneous data from disparate applications, its integration, sharing and use across the project phases.*
This paper is part of a large industrial research project, aimed to create an efficient engineering information integration framework. This framework will create a single, accessible and trusted data source, combining operational equipment data and its 3D representation. Previous papers published by the authors have presented the overall framework and the proposed technology to deliver the operational asset data. This paper focuses on linking that data to the 3D model elements, harvested from design applications, and delivering configurable and dynamic 3D scenes to the client's web browser. Performance benchmarks show the usability of the implemented Web3D prototype, based on WebGL, in a project environment.

KEYWORDS: *Digital facility asset, engineering information integration, Web3D, WebGL*

❖ INTRODUCTION

Information management in oil and gas industry covers both the creation of data sets and enabling data flows that are crucial to supporting the business processes (Hawtin and Lecore, 2011). The cost of creating or replacing missing information in the data set increases as the project progresses. It becomes very difficult and expensive to retrieve or recreate the missing information once the contractors have handed over the facility and associated information to the operation and owner teams (Rasys et al. 2014).
Equipment in an oil and gas facility is part of a very complex and interconnected asset. In addition to this challenge, projects in this industry suffer from information fragmentation. Data is generated by multiple applications, stakeholders and at different project phases. Due to the wide range of disciplines involved and applications used, data models often lack a well-structured and standardized information representation (Wiesner et al. 2011; Bayer and Marquardt, 2004).
Integrating data, including 3D model representation, in an information integration framework can help reduce this complexity. However, equipment data in this sector has a large number of operational attributes. 3D models in design applications are not suitable to store such amount of attributes from various disciplines. Project data warehouses are used to collect and store the equipment data; and 3D models include only equipment identifiers, referencing the model data in other systems.
Accessibility and the speed of access to information are important factors in the information integration framework (Rasys et al. 2014). The information needs to be available to multiple project stakeholders as project contractors in oil and gas industry regularly share information and responsibilities with the owner and subcontractors (Schramm et al. 2010). Project collaborators are often geographically dispersed or located in remote areas (Reece et al. 2008). Engineering web portals are deemed to provide a single immediate access to shared project information, enabling improved collaboration (Samdani and Till, 2007). To provide a single source of trusted engineering information, including 3D data, these web portals require an integration framework to help overcome the key challenges associated with the business processes in this sector:

- **Data mapping**. In greenfield projects - i.e. new oil and gas asset developments (Bell, 2012), which include populating new IT systems (Hopkins and Jenkins, 2008) - various parts of the overall dataset are made available at different phases of the project. In such projects, there is often a significant pressure on project schedules and design tasks are concurrently performed (Wiesner et al. 2011). As a result, 3D models are

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rarely available from the start and project collaborators are basing their work on preliminary data, which can change significantly over the course of the project.
In brownfield projects - i.e. existing, mature oil and gas assets, legacy IT infrastructure - data is present in various heterogeneous systems, which are populated by various companies. Collecting and aggregating data from such systems to assemble a single source of information is challenging, as conflicts in the data values, naming schemes and units of measure are common and need to be resolved.

- **3D content extraction**. Content creation applications are not suitable as the basis for information integration solutions because they are usually proprietary applications with closed data models. System developers do not have full control over the data models, which might be subject to changes with every new release. Therefore 3D content extraction into an application neutral format is needed to enable the successive reuse of data by other applications in the integration chain. An open file format, such as the Industry Foundation Classes (IFC) standard (Dibley et al. 2011; Schevers et al. 2007) adopted in the building industry, does not exist in the oil and gas sector.
- **3D content rendering.** Web3D (3D on the Web) technologies have not fully matured yet and web portals have limited graphic capabilities. Also mobile devices have limited network capabilities and their hardware resources (memory, processor and 3D support,) are relatively low. Desktop computers can be powerful and can have suitable network connectivity to provide a good web experience.
  WebGL (Parisi, 2012), which allows 3D visualisation in web browsers without the need of plug-ins, is becoming the new Web3D standard. As WebGL is a wrapper API (Application Programming Interface) over low level OpenGL functions, the 3D content extracted from the design applications cannot be directly rendered by a page just using WebGL. Therefore, to display the 3D content over the Web, additional libraries are needed to bridge the gap between the content generation and web applications. Also when considering web applications the data size of the 3D model have to be taken into account, as it can hinder the speed of the application and consequently its acceptance by industry practitioners.

While various research projects have tried to address specific aspects of the above challenges, an overall solution is still absent. In the remainder of this paper, we will present the findings from the review of related studies and propose a Web3D delivery framework and tool, as part of our overall information integration framework.

LITERATURE REVIEW

Integration approaches

In the process industry there have been several research projects addressing the challenge of information integration. Brandt et al. (2008) proposed an ontology based Process Data Warehouse system using knowledge integration. The system is based on KAON server (Oberle et al. 2004) and extended by OntoCAPE ontology (Braunschweig et al. 2004) to model the relationships between entities and enable decision support via semantic interpretation of queries. The authors chose scalability over the descriptive capabilities, available in description-logic based languages (Baader and Nutt, 2003). However the authors accept that the system is not efficient for large datasets, as it needs to load the entire information into memory.
Wiesner et al. (2011) further extended the use of OntoCAPE ontology to create a Comprehensive Information Base system for information and knowledge integration. They demonstrated with a prototype that the framework is suitable for processing industrial information and can offer modelling power via the hybrid ontology model. Their system, however, suffers from similar efficiency drawbacks to those encountered in its earlier version. A medium-sized dataset described in the benchmarks (521 items) took eight hours to process four integration queries. Only when the machine was upgraded to a 64 CPU (Central Processing Unit) one with 128 GB of RAM (Random Access Memory), the four queries took two minutes. Such an approach is not practical for data sources over 50000 items, which is often the norm in oil and gas projects.
Kim et al. (2011) presented an ISO 15926 based data repository (façade) to store equipment data throughout the nuclear power plant lifecycle. The framework prototype also includes the use of semantic web technologies and web services, so that other applications can interact with the project database. The authors suggest that the data sizes start in the gigabyte range in the beginning of the project, which increase to the terabyte range at the end of the project. In this case the selection of MySQL as the database engine is questionable, as the project does not show how the overall system performs with such datasets. Overall none of the proposed systems have a module for integrating and visualising the 3D data of the oil and gas facility.

Web 3D delivery and Building Information Modelling (BIM)

3D data is becoming a common BIM dataset in architectural, engineering and construction industry. The integration and delivery of 3D data have attracted significant attention in recent years. Chuang et al. (2011) recognised that existing proprietary BIM systems (e.g. Autodesk Revit, Bentley Architecture, Tekla Structures, etc.) are based on standalone frameworks and the information is difficult to access from different sites. To overcome this challenge, they proposed a Software as a Service (SaaS) approach using a server-based custom integration on the cloud. The solution incorporated RealityServer - a web service, integrating NVIDIA Tesla GPUs (Graphics Processing Unit) and 3D web services software (migenius, 2013). RealityServer was designed to deliver photorealistic 3D images to devices that do not have the power to render such images. The project chose a browser plug-in based technology - Microsoft Silverlight (Microsoft, 2014b), which enables the development of Rich Internet Applications (RIA). This, however, limits the compatibility of the solution, as it requires a desktop Operating System (OS) and a supported version of a web browser (Microsoft, 2014a).

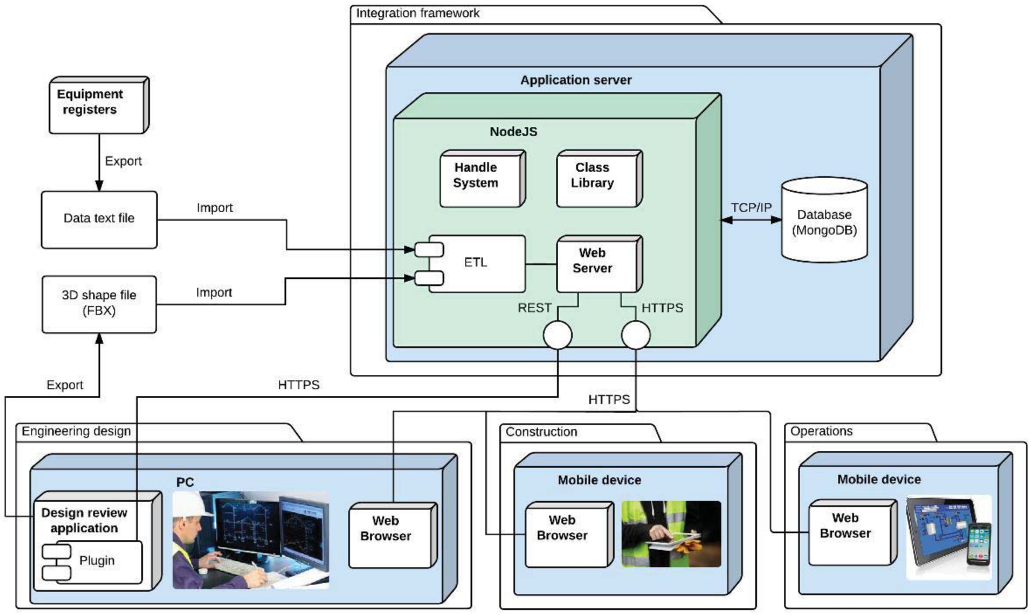
Hagedorn and Döllner (2007) presented a framework for integrating BIM models in the virtual city 3D models (CityGML). This framework assumed that BIM and 3D geodata were made available as web services. IFC was taken as a source format for BIM data and mappings between BIM and CityGML data were added to extend the CityGML model. The implementation of the visualisation was based on the LandXplorer technology – software system that enables presentation, exploration and analysis of geovirtual 3D environments (Autodesk, 2009). The complex 3D rendering was also done on the server side and the end result was then transferred to the client as image. While this approach enables photorealistic rendering of sites, it limits the interactivity as the user is not able to manipulate the scene.

A different approach has been presented by Beetz et al. (2010) in their BIMserver system. The IFC based framework was using an EXPRESS parser (Lubel, 2001) to produce in-memory data models in a Java based solution. The data was backed on a key-value store, and the solution included a prototype visualisation based on O3D – JavaScript API for building interactive 3D applications in the browser (Google, 2010). Subsequently BIMSurfer project (BIM network, 2011) has added a WebGL based visualisation client. Lack of documentation and dependency on the BIMserver makes it difficult to reuse the visualisation component of BIMSurfer in a custom project, not based on BIMserver.

To conclude, the research projects in the process industry seem to be ignoring the need for Web3D enabled portals. BIM solutions seem to acknowledge this gap, but the existing prototypes either fail to address the specific requirements of the oil and gas industry or are not sufficiently generic to be reusable in this context.

INTEGRATION FRAMEWORK OVERVIEW

The ultimate outcome of this research and development project is an engineering information integration framework which serves as a basis for a commercial SaaS solution. The framework uses a central information database, which is being populated by loading in files in a plain text (tab delimited) format (Fig. 1). It is difficult to achieve an automatic system integration without an extensible format (e.g. XML or JSON), but this is not a requirement due to the heterogeneity of the applications involved (design/review software, Microsoft office tools, ERP systems). Such an approach allows end users to extract and transform the data from text files using common data processing software - e.g. Microsoft Excel, Talend Open Studio (talend, 2014), etc. It also makes it possible to utilise data from systems that are not always online, or provide access only to snapshots of the data due to security reasons.



The system utilises a simplified ontology called Class Library. Class Library defines the equipment attribute requirements, which change during the project. It also defines a set of mappings for various data sources (e.g. text based datasheets, 3D model extracts, etc.), which are used to resolve naming conflicts and map data into unique entities with an extended set of attributes within the database.

As JavaScript is a de facto programming language used in modern web browsers, the framework has been implemented on a JavaScript based Node.js server engine (Joyent, 2014). Such implementation eases the system development as the data model only needs to be expressed in the constructs of one programming language (JavaScript). The system delivers data over a web portal and REST (Representational State Transfer) API. Web interface allows a convenient and immediate access to information on various devices, without the need to install any additional software. The web application can also be integrated into a company's web portal. The REST API interface provides data for the plug-ins in desktop applications (e.g. NavisWorks), which can then retrieve additional project information for the selected geometry shapes within the desktop application. Cloud based solution is suggested by default, as this provides the best availability and scalability options, but it can also be deployed inside an internal company network.

Such a system requires an efficient storage engine. A semi-structured database system has been chosen for this project (Rasys and Dawood, 2012). It provides a balance between performance and functionality, providing an adequate level of reliability with the possibility of scaling up for large deployments. The database is capable of storing and querying the JSON objects directly; therefore the manipulation of the data becomes much easier in a JavaScript based framework.

Scene extraction and segmentation

In the prototype mapping implementation (Fig. 2) the model is exported from Autodesk NavisWorks into a text based FBX file. The 3D scene is triangulated – parametric shape definitions are converted into a polygon mesh. This increases the size of the 3D dataset and reduces the accuracy of representation, but greatly simplifies the processing logic, when providing data to the client rendering engine. The FBX file is processed by a Python script, which triangulates the scene objects using the FBX SDK Python bindings (Autodesk, 2014).

A single piece of equipment is usually modelled as a group of simple geometric shapes. Therefore the shapes

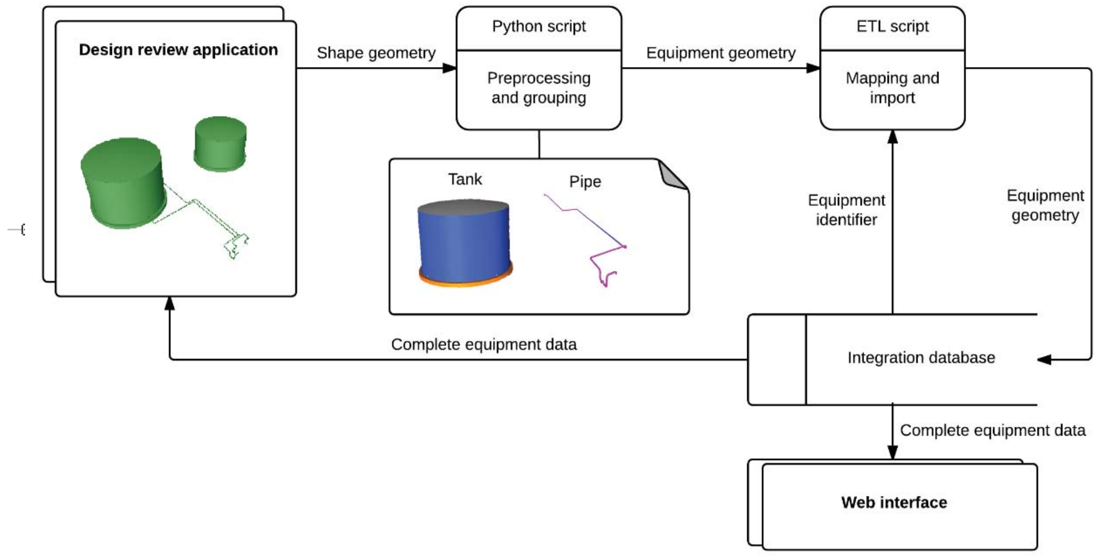
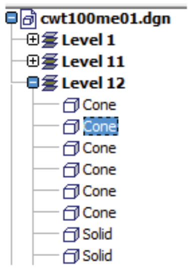


Fig. 19: mapping, aggregation and integration of 3D model elements

need to be grouped into equipment shape sets by identifier data present in the model. A tree node structure is used to organise the overall scene and usually no node or shape contains the actual equipment identifier. The identification data depends on the design application used, project naming, modelling conventions, etc., as shown in Fig. 3 and 4. As the data is often produced by different contractors it is often impossible to produce reliable 3D model equipment mappings to the equipment data supplied by other stakeholders. Therefore the mapping is usually a labour intensive process, which requires engineer input.
In the first example (Fig. 3) a pipeline is modelled by multiple shapes in the scene tree, none of which matches the actual pipe identifier in the database (*4"-VA-032-348-CB03-NI*). In the second example (Fig. 4), the shapes are not grouped in the scene tree by equipment; each of them has equipment identification data, which also does not match the equipment identifier in the database (*KHA-T-440003*). Due to such inconsistencies in the modelling practices, the mapping procedure cannot be fully automated and has to be configured specifically for each project.



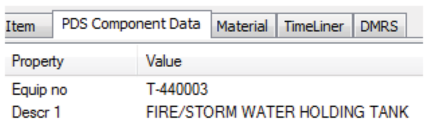


Fig. 20: Model with the part of an

Fig. 21: Model with the part of an identifier in the additional

During the ETL (Extract, Transform, and Load) import process the shapes are grouped into collections, representing the same equipment item. This is done based on the information present in the node tree (Fig. 3). As the FBX file format does not contain the additional shape attributes, visible in Fig. 4, the integration is currently not possible with this type of modelling practice. After the shapes are grouped to parent nodes, their names are processed – the string */VA-032248-06-B1* is transformed into *VA-032-248* and then a partial match query is executed on the equipment identifiers in the database. As the match is found (*4"-**VA-032-348**-CB03-NI)*, the equipment geometry is associated with this particular database entity.
The full data model of an Oil & Gas facility is usually a large and complex 3D object, which is best viewed on screens with large resolution. Also the triangulated 3D scene takes significantly more space than the original

model; hence its delivery to mobile devices with slow network throughput could be challenging. Instead of scene simplification, a dynamic scene delivery is proposed to improve the user experience.
The user is usually interested in seeing the visualisation of a particular area of interest e.g. a location in the plant, equipment in a particular work package or change order, items with a certain attribute value, etc. Instead of loading the whole model and then hiding the unnecessary elements, the framework only fetches the data that is relevant for a particular query. Such scene delivery also allows applying access control rules over certain item data, including the 3D representation.

Dynamic scene rendering using Web3D

Web3D object visualisation implementation is based on WebGL technology. As WebGL is a wrapper API, representing OpenGL functions, a JavaScript scene graph library, three.js (three.js, 2014), is used to simplify the 3D content display. It abstracts the more complex mathematical calculations needed (e.g. matrix multiplications for projections, lighting and visibility calculations, etc). The library is able to dynamically construct a scene or add objects to a scene. When incorporated into a web portal, the approach allows dynamic scene composition based on a configurable view. The system retrieves only those 3D shapes that are needed to visualise the items, selected in the browser, and renders them in a custom scene (Fig. 5 and 6).
It has been observed that for larger scenes the HTTP requests can time out because of the size of the data that needs to be downloaded from the server. To overcome this issue a 3D streaming prototype based on WebSocket protocol (Fette and Melnikov, 2011) has been implemented. WebSocket protocol is designed for an efficient bi-directional communication between a client and a server application. Current versions of the most popular browsers (i.e. Chrome, Firefox, and Internet Explorer) natively support this technology. A socket.io library (Open-Source, 2014) is used to abstract the complexity of the protocol; it also provides compatibility with older browsers, where the software automatically falls back to using an XMLHttpRequest (W3C, 2014).

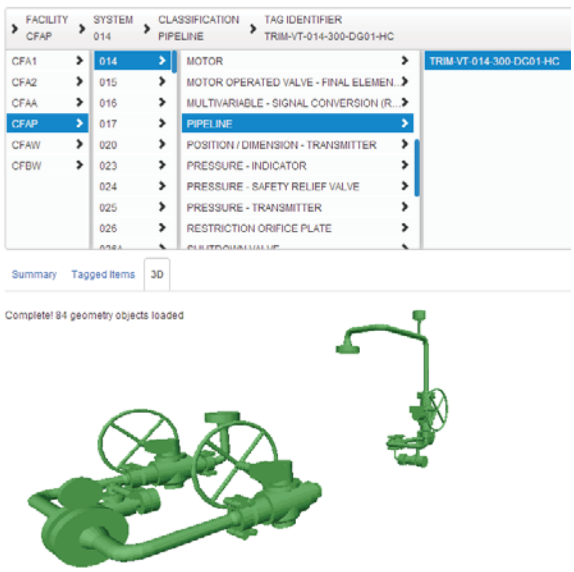


Fig. 22: visualising a single complex pipeline

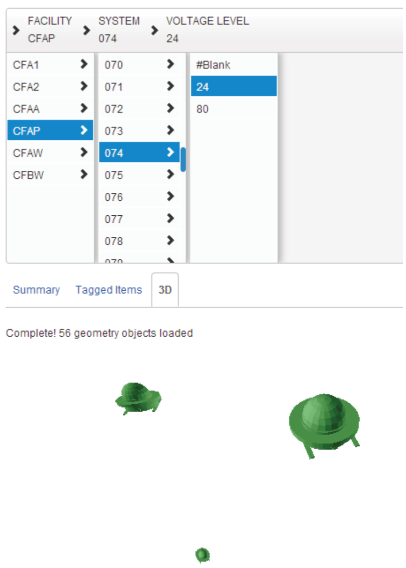


Fig. 23: visualising all items, which have a

VOLTAGE LEVEL = 24V

The speed of the 3D scene delivery is a function of network latency (a delay between requests and responses), network throughput (speed of data transfer), web server and database performance, browser performance, complexity and accuracy of shape geometry (which affects the size of the data that the users have to download), the number of simultaneous users, etc. Additionally, because of the implementation of the socket based streaming, it is problematic to automate the system benchmark using the existing testing tools, such as Apache JMeter (Apache Software Foundation, 2013). Because of this, the metrics were collected in the web browser

(Google Chrome v35), measuring the time it takes for the system to render the scene – starting from the submission of the initial request and ending with the moment, the last socket message is received (Fig. 7).

As testing in multiple networks with predefined speeds is impractical and results would not be comparable, tests were executed on a single fast network with around 90Mbit throughput to allow ample room for unexpected network activity. To simulate slower networks a bandwidth limiting software NetBalancer was used with various speed settings, which represent the real world scenarios.

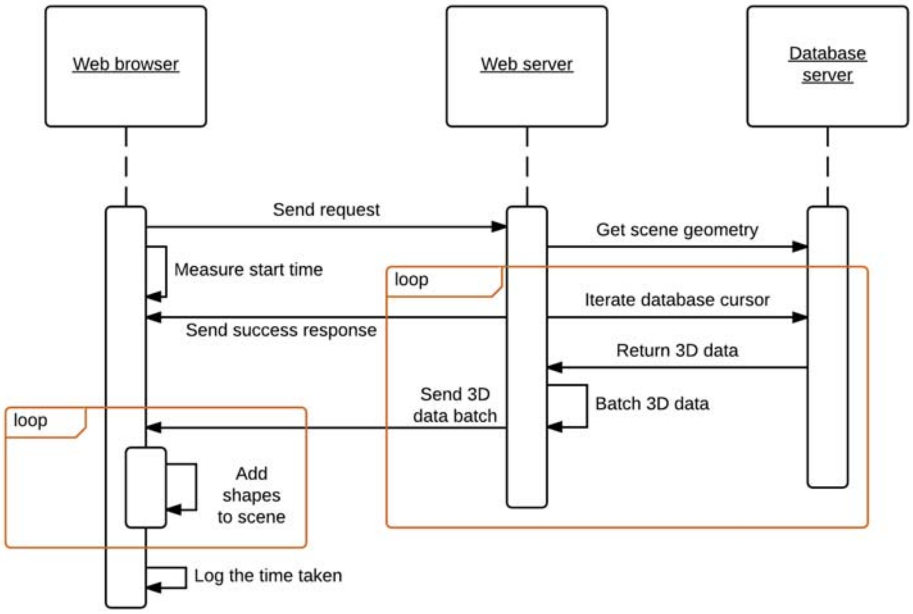
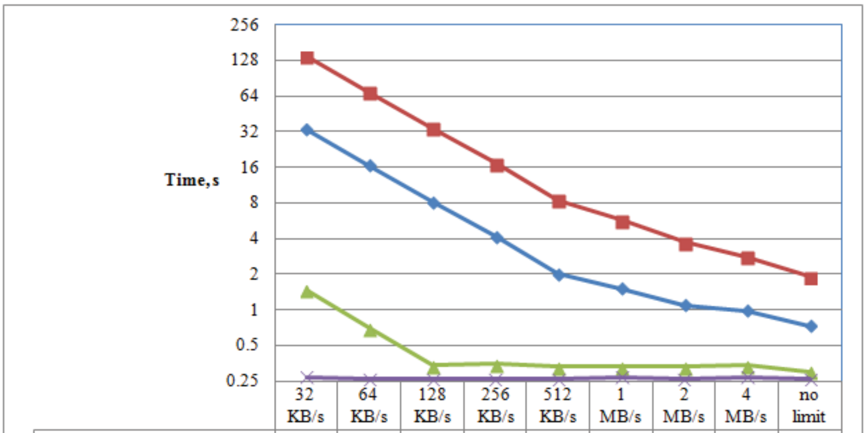


Fig. 24: The scheme for testing the speed of the 3D streaming service

The database/web server was based on Amazon AWS cloud infrastructure in Ireland, which also has ample reserve bandwidth available, and the measured round-trip network latency (ping) to Ireland was 25ms. All tests have been executed five times, the highest and lowest values were discarded and then an average result was calculated from the remaining three values. The performance testing results are presented in the Figure 8.



	32 KB/s	64 KB/s	128 KB/s	256 KB/s	512 KB/s	1 MB/s	2 MB/s	4 MB/s	no limit
4.26 MB (loading time, s)	138.06	68.99	34.44	17.22	8.51	5.7	3.74	2.82	1.9
1.03 MB (loading time, s)	33.26	16.66	8.18	4.14	2.02	1.51	1.1	0.98	0.73
48 KB (loading time, s)	1.46	0.7	0.34	0.35	0.33	0.33	0.33	0.34	0.3
3.3 KB (loading time, s)	0.27	0.26	0.26	0.26	0.26	0.27	0.26	0.27	0.26

Fig. 25: Loading times depending on various network speeds

RESULT ANALYSIS

The result analysis shows that the overall system latency on average is around 0.26 seconds – this is the duration of the whole request-data retrieval-response-render cycle with the minimal amount of data (3.3KB) and a very simple geometric shape (cube). The bottom two lines represent very small scenes and show that different baselines exist for different scene sizes. Increasing the network speed beyond those baselines does not result in a faster scene delivery. For larger scene sizes and when the scene loading time is higher than the baseline, the graphs show approximately a linear dependency between the loading time and the speed of the network. For slower speeds a 50% increase in network throughput also decreased by loading time by 50%. For faster speeds the dependency is not linear as other factors (speed of the server, browser capability to load a big scene, etc.) also become apparent.

Literature disagrees on the acceptable loading times for web applications. Some data shows that delay of up to 10 seconds is acceptable for the users to keep their attention and interest (Nielsen, 2014), provided a loading indicator is present, showing when the system is going to finish the task. Other researchers came to varying conclusions, although it seems that many have observed a change in behaviour between two and four seconds (Nah, 2004). In the tested configuration a medium scene with 4MB of data (132 equipment items) could be usable on a 512KB/s (4Mbit) internet connection, while the recommended network bandwidth is at least 2MB/s (16Mbit). As the loading time largely depends on the scene size, it is obvious that the web application accessed on a computer inside an office could deliver a larger scene within an acceptable timeframe than on a laptop with only mobile broadband available.

The size of the full oil and gas facility mesh model is at least multiple gigabytes. The prototype system reaches the limits of the recommended latency with the 4MB scene, therefore benchmark tests with larger scenes were not attempted.

DISCUSSION AND CONCLUSIONS

The backend of the integration framework has proven to be able to operate on large quantities of data (millions of items) (Rasys and Dawood, 2012). As the client side views are based on Web technologies, it offers an immediate access to the project data on a multitude of devices, although the web site usability is limited on devices with small screens. This can be improved by designing a separate, mobile version of the website or writing specific applications for mobile devices.

As the JavaScript engines inside the browsers abstract the hardware resources of the client machines, the performance of the client JavaScript code is unlikely to achieve the performance level of highly optimized, platform specific software written in a low level language (e.g. C). However, the JavaScript engine performance is constantly improving and there are several projects addressing the optimisation of the JavaScript compilers (Resig, 2013).

The issue with the data size of the 3D content is also apparent as the system is capable to deliver a certain amount of items that can be streamed in a reasonable time. Transferring a gigabyte of data over a Fast Ethernet network (100Mbit/s) takes more than a minute. In order to transfer large oil and gas facility model scenes and potentially the full model, the size of the dataset has to be addressed first. One potential solution is to investigate the parametric shape visualisation, which is considered to be more compact than the polygon mesh dataset. This will reduce the amount of data needed to display 3D objects and consequently increase the possible scene sizes.

Another potential solution is data compression and mesh simplification. A number of projects exist which address the issue (e.g. Li et al. 2007). While this potentially reduces the fidelity of the visual representation, it might be necessary to achieve a balance between the user expectations and the system usability.

The relatively low possible object count in a scene (up to hundreds of items) prevents the usage of the system in some of the more complex scenarios (e.g. clash detection, full facility visualisation and simulation, etc.). However, the proposed framework and tool is considered adequate for visualising a limited set of equipment or a small assembly of objects. Because of the dynamic nature of the generate view, the system can assemble views on any attribute stored in the database.

Such functionality is valuable for data mangers and maintenance engineers. The system adds a 3D representation into the custom data views for data managers. Maintenance engineers can visualise the equipment and their attributes before and during a work order execution.

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DEVELOPMENT AND EVALUATION OF AN ACTION-BASED EDUCATIONAL SERIOUS GAME ABOUT DISASTER EVACUATION[1]

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ABSTRACT: *Serious games, which are games designed for a specific purpose rather than pure entertainment, have begun growing in popularity in recent years. In this study, a serious game that aims to facilitate disaster evacuation education was developed and its effectiveness evaluated. The terms "goal," "interaction," and "quantification" were extracted from literature analysis as the characteristic factors of game, and the serious game central to this study was developed and evaluated according to these factors. The game was designed to teach the positions of stairways and evacuation apparatuses while a user navigates the virtual environment to rescue injured victims. An experiment was conducted and the result shows that learning effectiveness was enhanced by the serious game. Clarification regarding the suitable distribution of the characteristic factors and development of a framework for serious games are required in future endeavors.*

KEYWORDS: *serious game, evacuation training, digital game, facility management, simulation, virtual reality*

❖ INTRODUCTION

An earthquake is a phenomenon whose occurrence is difficult to forecast, and large-scale one that occurs suddenly will cause a large disaster by damages of building, lifelines, and infrastructures, and dangers in human life. Rapid evacuation from collapsing buildings is needed after the quake, however, route-finding is difficult in the large buildings especially in cases that many obstacles emerge by the earthquake. Moreover, the life-saving and evacuation assistance for injured people are required in many cases. Although evacuation trainings are performed periodically to experience the actions in an instance of disaster, it is difficult to learn actions in the various situations because one exercise can target just one case. Computer simulation is effective as a mean to reproduce various cases virtually, and many researches using simulations to analyze human behavior in disasters are done (Pel et al., 2012). Evacuation simulators that equipped virtual reality equipment and environment have also developed in recent years (e.g., Mol, 2008). Nevertheless, these simulators aim only to experience the situation, and they are not prepared to learn actions in various cases.

This research focuses on the learning effectiveness by serious games and examines to apply the serious game for action-learning for evacuation in disaster. The term "serious game," which was used before the appearance of digital games (Abt, 1975), means a game designed for a specific purpose rather than entertainment. In recent years, efforts to apply serious games have been made in various fields, such as education, military, and healthcare (Susi et al., 2007), and the market for serious games is growing (Alvarez and Michaud, 2009). Researches on serious games show that serious games improve motivation and provide a system of classification (e.g., Breuer and Bente, 2010); however, theoretical research on game factors, know-how, etc., has not yet been fully conducted.

In this study, we first extracted the characteristic factors of serious games, developed a serious game for teaching people about evacuation during a disaster that is based on those extracted factors, and then evaluated the game's training effectiveness.

CHARACTERISTIC FACTORS OF SERIOUS GAMES

Purpose and items to learn

The serious game that was developed during this research aims to educate the user about disaster evacuation. The goal of the player is to evacuate quickly while rescuing other victims of the disaster. Learning specific items in the process is useful, such as knowledge about the location of the disaster event, the number of stairs, evacuation equipment, and how to perform first-aid for the victims. In the development of this game, the

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distribution of these characteristic factors was considered.

Characteristic factors for serious games

This paper discusses the characteristic factors of the game in reference to literature about the definition of “game” and “play”(Caillois, 1961; Costikyan, 1994; Crawford, 1982; Duke, 1974; Juul, 2003; Salen & Zimmerman, 2003). Those factors were divided into the following seven items:

(1) freedom (2) rules (3) entertainment (4) unrealistic

(5) goal (6) interaction (7) quantification

The game-specific factor can be extracted by eliminating factors which “game” and play” commonly have.. Referring to the literature by Caillois (1961), (1), (2), (3) and (4) can be classified into the common factors and excluded; (5) goal, (6) interaction, and (7) quantification are selected as the factors that are game-specific.

The contents of the characteristic factors of the game that are incorporated and evaluated in the development of serious games at this time are as follows.

(a) goal

The goal is the desired end result the player is aiming for in the game. In the serious game of this study, evacuation is the main goal, and rescue is a secondary goal. In the process of a player achieving his/her goal, items, such as positions of stairs, fire extinguishing equipment, and knowledge of first-aid, are distributed in the space in order to improve the learning effect.

(b) interaction

Interaction between a player and a game is a factor directly related to the fun of a game. The player’s actions regarding obstacles and the victims on the map are fed back to him/her in terms of both the progress of the game and the evaluation.

(c) quantification

Quantification is the factor that measures the success or failure of an action and the degree of influence that player’s action had. In this game, a fixed quantity for the success or failure of evacuation, the success or failure of an obstacle breakthrough, the number of rescued victims during evacuation, and the overall evaluation are given to the player.

DESIGN AND DEVELOPMENT OF SERIOUS GAMES

Scenario

The player’s objective is to evacuate from a building. However, a learning effect could not be obtained by this goal alone because the whole map would not be patrolled. Moreover, there would be little entertainment value or interest. Then, the injured victims who could not escape were distributed on the map, and the player’s task also included performing rescues. While aftershocks from the main earthquake continue, a player attempts to rescue and evacuate victims in cooperation with a friend that they meet on their way inside the collapsing building.

Game rules

Energy is given to the player’s character as a numerical value, and they fail to escape if all energy is lost. Though evacuation is possible from every stairway, many obstacles are set on the course to the stairs, and a player advances by using items to break through these obstacles. Moreover, the evocation of motivation is urged by play evaluation. The score is determined by time taken to complete evacuation and the number of rescued victims.

There are three roles in placing injured victims on the map. The first is compelling a player to explore the entire map while searching for victims, thus learning the positions of fire extinguishing equipment and stairways. The second is compelling a player learn the correct emergency measure to use on an injured person. The injured or sick person who needs an emergency measure is stationed in the game, and the player must acquire knowledge of the proper emergency measure to use. The third is adding an element of fun to the game. Although the score is determined by play time and the number of rescued victims, as the rescued number increases, the stairs that can be used as an emergency exit collapse. With this specification, the challenge of balancing between shortening play time and increasing the number of rescues can be enjoyed.

Game development

The game was developed as a role-playing game using “RPG Maker VX Ace” by Kadokawa Corporation. Captured images from the developed game are shown in Figure 1.

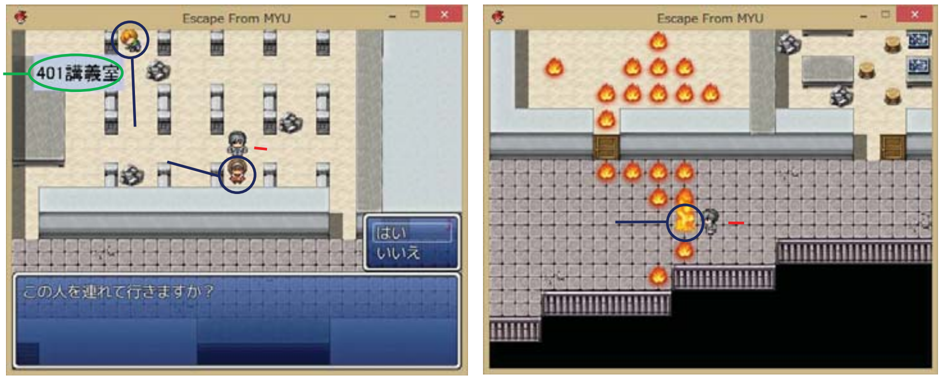

Fig.1: Captured images of the evacuation game.

EVALUATION OF A SERIOUS GAME’S EFFECT ON LEARNING

Experiment

The effectiveness was measured for serious games that have been developed. In this experiment, the subject building is the Miyagi University headquarters building, and a part of the building has been implemented as a map in the game (Figure 2). The building structure of the area in reality, such as fire extinguishing equipment, etc., has been reproduced on the map. There were 14 valid responses from 14 subjects comprised of students and faculty. Most subjects experienced the evacuation training operated by the university once a year.

The effectiveness measurement was determined by comparison of a paper test score of the subject given both before and after game play. The test contained a question about the number of stairs in the area, a fire escape apparatus and fire extinguishers, and a multiple-choice problem about the correct emergency measure to use in response to a fracture, bleeding, a burn, and consciousness disorder. Moreover, for ten of the subjects, a questionnaire survey about the characteristic factors of the game was conducted after the written examination.

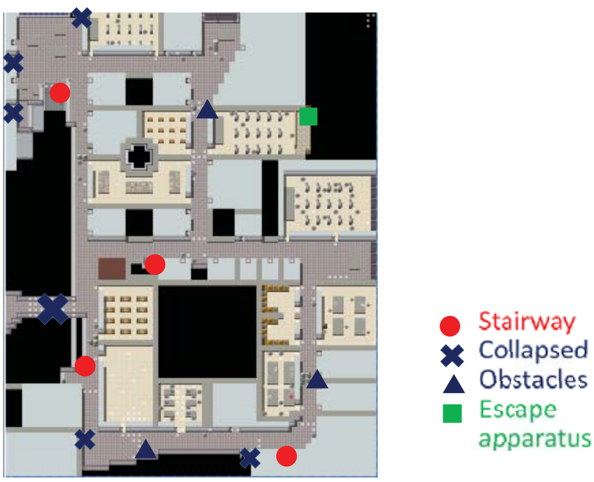

Fig. 2: Implemented map results.

Result and Evaluation

Figure.3 shows the change in the average number of errors made when answering questions about each piece of equipment. For the number of stairs, the difference in the average incidence of error before and after play was almost the same. For the number of fire extinguishers, the average number of errors was -9.3 before play, and after play, it was -3.7; the error average was decreased by 5.6. The number of errors about fire escape apparatuses was 3.9 before play, and after play it was zero; the average number of errors was reduced by 3.9.

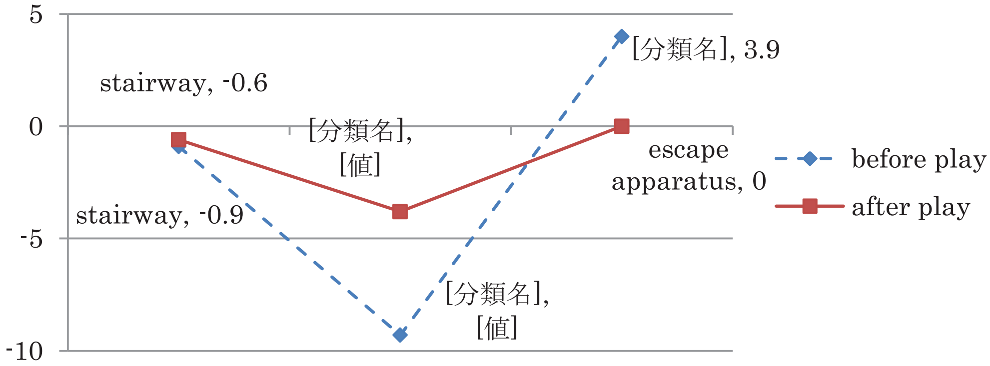

Fig. 3: Comparison of error average before and after playing.

Figure 4 shows the change in the number of correct answers about emergency measures. Regarding the question about the emergency measure for a fracture, 13 people answered correctly after play while only 10 people gave the right answer before play. For the question about the emergency measure for bleeding, 13 people answered correctly after play and only 6 people gave the right answer before play. Regarding the question about a burn, after play there were 12 people who answered correctly and 8 people gave the correct answer before play. For the question about consciousness disorder, 14 persons answered correctly after play and 13 people gave the right answer before play.

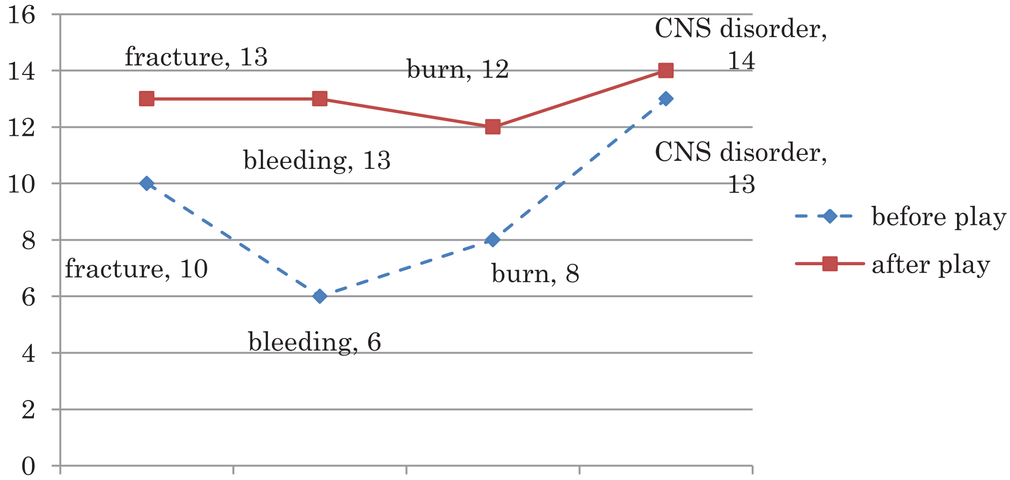

Fig. 4: Number of correct answers about emergency measures.

Moreover, on the questionnaire administered after play, questions were asked about the fun and the characteristic factors of the game. Regarding fun, it was asked whether, compared with the actual training, it is interesting, and nine people among ten responded that it was

Regarding the characteristic factors of the game, three choices were given about the goals, the interaction, and the quantification, respectively.

The following three choices were set up about the goals.

Choice A: Only evacuation and rescue are required.

Choice B: You should increase the number of goals.

Choice C: You should extract a goal, either evacuate or rescue.

Regarding the interaction, the following choices were given about the obstacle or the number of events in the game.

Choice A: The present number is just right.

Choice B: You should increase them.

Choice C: You should reduce them.

Regarding quantification, the following three choices were given about the numerical value and the last evaluation displayed in a game.

Choice A: The present condition is just right.

Choice B: You should make it more detailed.

Choice C: You should make it simpler.

The results are shown in Figure 5. For the goals, Choices A and B obtained 4 responses; for interaction, Choice A obtained 7 while B obtained 3; and for quantification, Choice A obtained 8 while B and C obtained 1.

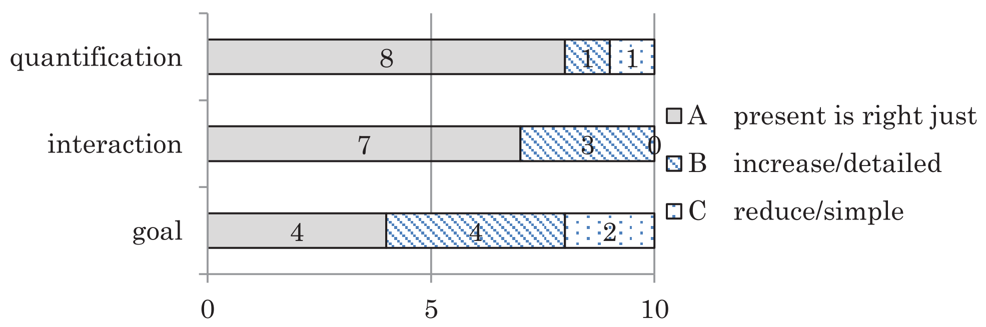

Fig. 5: Evaluation of the quantity of characteristic factors.

As the result of experience, regarding the number of stairs, since the subject was using stairs daily, the differences in errors before and after play were few. On the other hand, the errors about fire extinguishers and fire escape apparatuses could be reduced greatly and the numbers of the correct answer of emergency measures increased. These results show that the subjects could obtain the knowledge about the positions of evacuation equipment and emergency measure that they had not known through actual training and daily activity only by playing the game. Furthermore, most of the subjects feel fun compared with actual training. It is shown that the game is useful as a means to give required knowledge without being conscious of learning. Although this evaluation focused on knowledge acquisition by the game, effectiveness of memorization should be evaluated in future.

In addition, from the audit observation of a subject's game play, some scenes where the subject was bewildered by the operation of the game were seen, and it is thought that the tutorials about the game are insufficient. A device that enriches the help that a player receives in advance of game play is required.

CONCLUSION

In this research, the characteristic factors that are important in a serious game were extracted, an action-based educational game about disaster evacuation was developed based on those factors, and an experiment to evaluate its effectiveness was conducted. As a result, it was shown clearly that a serious game has an effect on learning that is acquired by keeping the players' interest.

A major problem of serious game development is scarce pliability, because serious games need to be developed on a case-by-case basis. Therefore, a framework for serious games needs to be developed. It is also necessary to clarify the suitable distribution of the characteristic factors of a game through a pattern test, etc. Moreover, by clarifying the development technique of a serious game from an analysis of the characteristic factors, application will become more active in various fields, including architecture, engineering, and construction.

ACKNOWLEDGEMENT

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VISUALIZATION TOOLS FOR ENERGY AWARENESS AND MANAGEMENT IN ENERGY POSITIVE NEIGHBORHOODS[1]

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ABSTRACT: *In an Energy Positive Neighborhood (EPN) the annual energy demand is lower than annual energy supply from local renewable energy sources. Short-term imbalances in energy supply and demand are corrected with national energy supplies. In this paper, some tools for intelligent management of energy positive neighborhoods are presented. These tools include an energy management tool for real-time management of the energy flows, user interfaces that support energy efficient behavior of the users in the neighborhood and an urban planning decision support tool. These tools have been developed as part of a European co-operation, and are designed so that they can easily be adopted in different European countries with minimum changes. The focus of this paper is the description of the developed user interfaces for energy awareness and management in an energy positive neighborhood.*

KEYWORDS: *Energy positive neighborhood, energy management, visualization, user interfaces*

❖ INTRODUCTION

The EU FP 7 Project "Intelligent Neighborhood Energy Allocation & Supervision" (IDEAS) aims to demonstrate how energy positive neighborhoods (EPN) can be cost effectively and incrementally implemented by designing, testing and validating various software tools and user interfaces. The primary intended user of the tools developed in the IDEAS project is a new type of actor, the energy positive neighborhood service provider (EPNSP, described in Crosbie et al 2014). Currently this actor does not exist as such, but is represented in the project by an energy company at a Finnish residential demonstration site and a facility manager at a university campus in Bordeaux, both of which could be the central actor in the business model. In the business model, some key activities are supported by the control and optimization tools and user interfaces, as well as the decision support tool for urban planning:

1. A neighborhood energy management tool to optimize energy production and consumption;
2. User interfaces that engage communities and individuals in the operation of energy positive neighborhoods;
3. A decision support urban planning tool to optimize the planning of neighborhood energy infrastructures;
4. Business models to underpin energy positive neighborhoods that engage end users, public authorities and utility companies.

The focus of this paper is to report the prototype user interfaces which have been developed as part of the IDEAS project. These user interfaces are a set of software tools. The user interfaces provide intuitive environments that engage casual users and in doing so improve their energy literacy and energy consuming behaviors. The access to the management system data will be provided using web technologies to enable both facilities managers and residents to take advantage of the information presented on the provided interfaces. These user interfaces have been developed based on the specifications originally presented in (Shvadron 2013). These user interfaces will be used at two neighborhood pilot sites within the context of the IDEAS project. These include the University campus in Bordeaux, France and a newly built residential area in Porvoo, Finland. The user interfaces developed cover all the aspects of how users in both IDEAS pilot sites can act and what they will experience as a result of those actions.

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[1] Citation: Short, M., Dawood, M., Crosbie, T., Dawood, N. & Ala-Juusela, M. (2014). Visualization tools for energy awareness and management in energy positive neighbourhoods. In: N. Dawood and S. Alkass (Eds.), Proceedings of the 14th International Conference on Construction Applications of Virtual Reality, 16-18 November 2014, Sharjah, UAE.

USER INTERFACES FOR ENERGY AWARENESS AND MANAGEMENT

Following user interfaces for energy awareness and management have been developed so far:

1. A shared 3D virtual space, which allows visitors to see and interact in-context with people and visual information related to the energy usage and production in the pilot site in France.
2. A home energy management system which is composed of: (1) an application which displays energy related information on the home TV and (2) a handheld augmented reality application. The goal of both is to help home residents to act upon energy conservation requests and intuitively make decisions on how to optimally achieve their energy demand goals. These applications will be tested over a 9 month demonstration period and results will be obtained to show their effectiveness.
3. An "energy awareness" user interface, which will be installed on wide screens in public spaces within the French pilot site and the Finnish pilot site.
4. Energy awareness tools dedicated to a site Energy Manager (the EPNSP) that were developed in order to better understand how a site consumes and produce energy, and to visualize the output of the energy optimization process."

USER INTERFACES SYSTEM LAYOUT

In order to realize the above functionality, an IT infrastructure has been designed (see Figure 1). This infrastructure consists of a central Smarter Cities and Energy Management System (EMS) (Short et al 2013) which handles and manages all the energy related information for the energy positive neighborhood. Lower level details of the IT infrastructure are given in (Short 2014a and Dawood 2014b). A web interface allows the various user interfaces that serve each pilot site to access the data and interact with it for the above purposes. As can be seen in Figure 1, the IDEAS IT system is designed so that one piece of software can cater for both case study sites. This flexibility demonstrates the potential of the results of the project to be applied in differing areas, thus increasing its ultimate exploitation potential. The EMS is designed to be capable of providing energy management services to several types of EPNs such as those in the IDEAS project – a neighborhood and a large institute. An Urban planning tool (Ala-Juusela et al 2014) provides the ability to design EPNs and provide long term insight of its potential. The IT layout for the local EPN in Porvoo is illustrated in Figure 2.

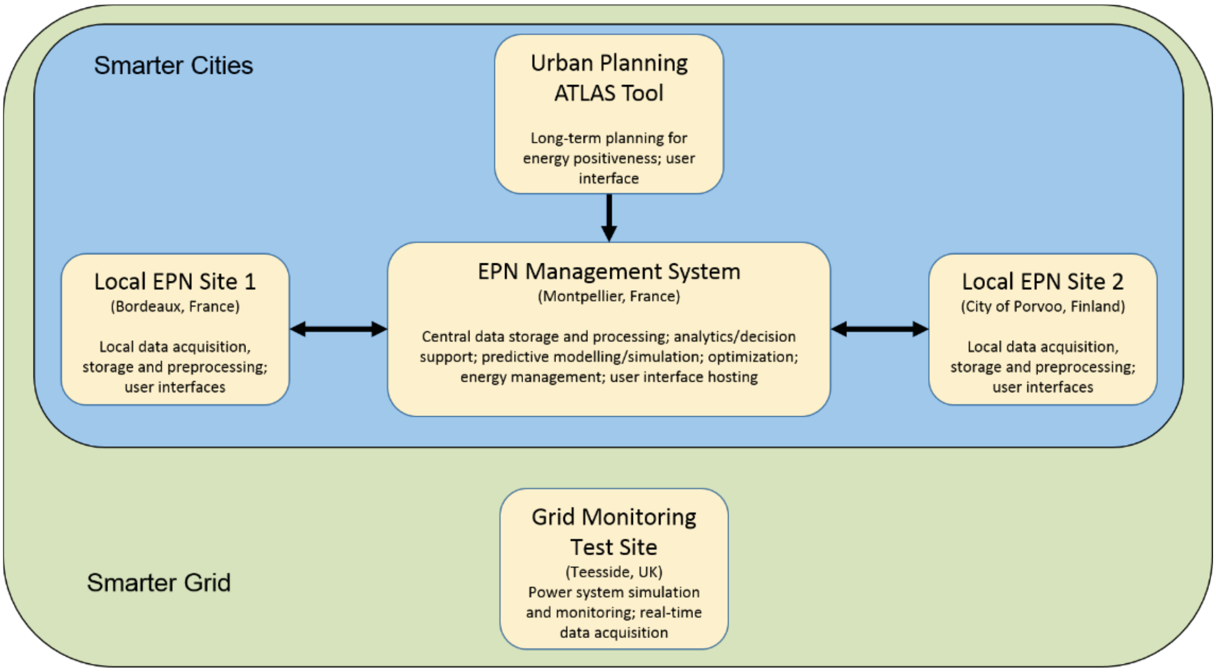

Fig. 1: High-level overview of demonstration sites, IT tools and functionalities in the IDEAS project

The user interfaces in Porvoo are marked in red in Figure 2. These interfaces are:

- Large interactive screens located in the Omenatarha nursery and in the city of Porvoo municipality building. These screen provide EPN related information to the residents of Porvoo
- Home applications that provide the resident detailed information about the energy consumption at home.

This information is displayed on the home TV using an application that runs on a small Android device (MK908). Another application which runs on an Android tablet provides real-time information on the energy consumption of specific home appliances using augmented reality. The energy information is provided by sensors that are connected to the devices.

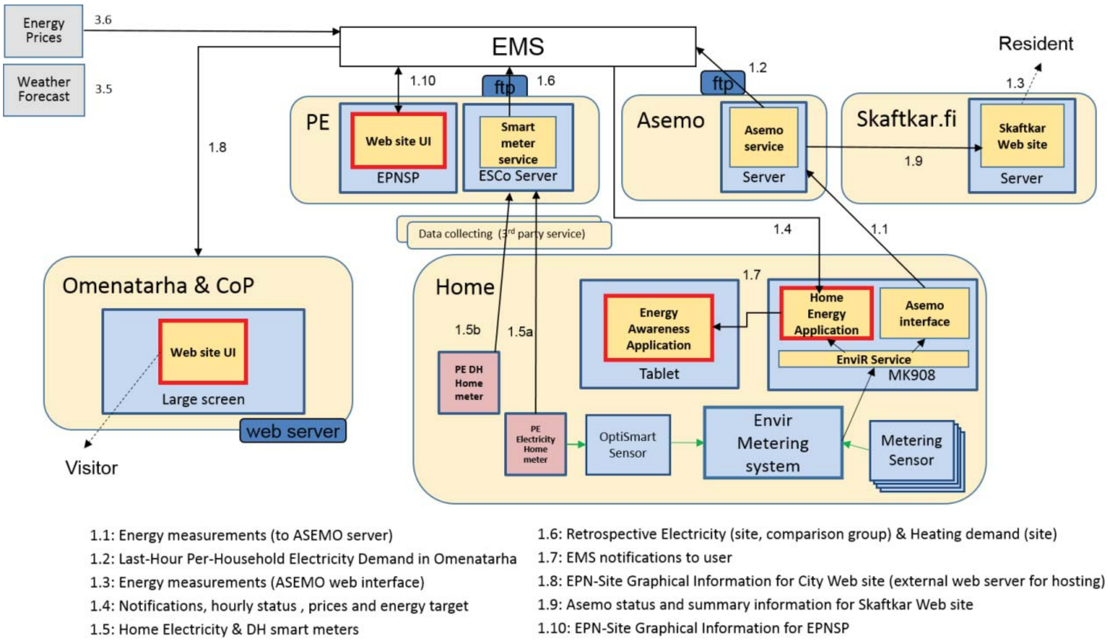

Fig. 2: IT system in Porvoo

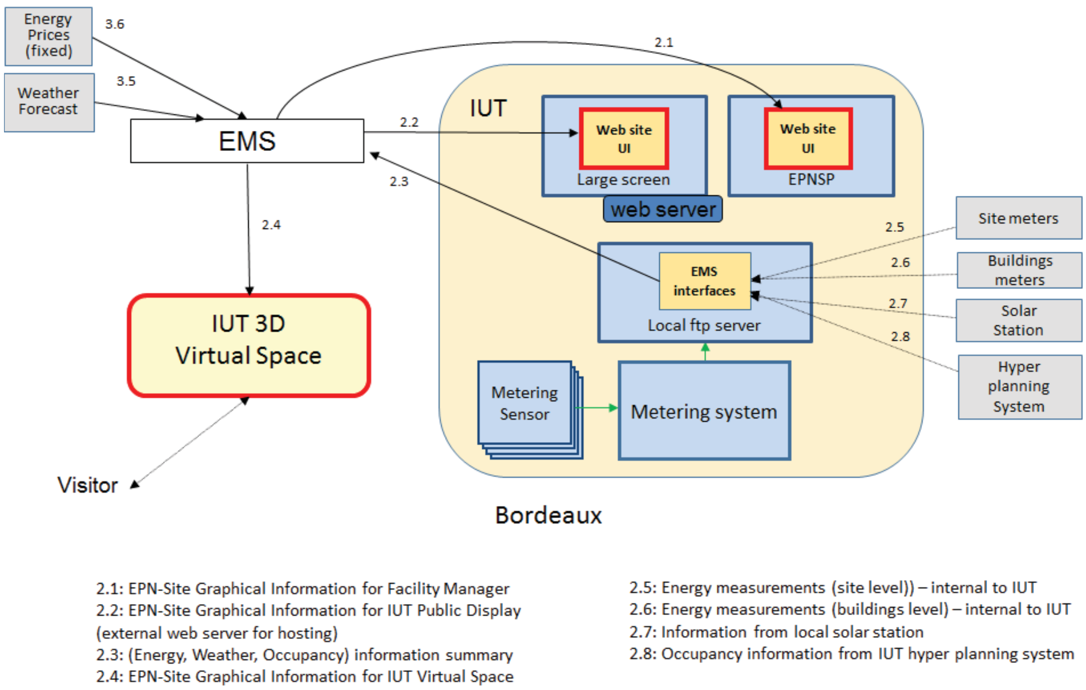

Fig. 3: IT system in Bordeaux

- EPNSP web site provides energy related professional information that enables managing the EPN

The IT layout for the local EPN in Bordeaux is illustrated in Figure 3. The user interfaces in Bordeaux are marked in red. These interfaces are:

- Large screens located in several key places in the IUT buildings. These screen provide EPN related information to the local students, local employees and visitors
- EPNSP web site provides professional energy related information that enables managing the EPN
- A 3D virtual space that enables external visitors to learn about the EPN in IUT. This interface emulates the actual IUT facility with respect to various energy consumption and production aspects.

DEVELOPED INTERFACES

Augmented reality based home Interfaces

This interface was developed in order to realize one of the main goals of the IDEAS project, namely to inform home residents about fine grain energy consumption and to help them meet the energy supply objectives of the Energy-Positive Neighborhood (EPN). During the IDEAS project pilot period the residents of a Finnish neighborhood in Porvoo will be notified by a neighborhood Energy Management System (EMS) about potential actions that could be taken to reduce peak energy demand and shift energy demand to periods when renewable energy is available.

For this purpose two applications have been developed, the Home Energy Application (HEA) and the hand held Energy Awareness Application (EAA).

The HEA application provides the resident detailed information regarding the energy consumption of their home as well as information about the current overall status of the EPN in which they live. The information is provided on the home TV by an application that runs on a small android device (MK908) that is connected to the TV. This device is connected to electricity measurement equipment that measures the electricity consumption of appliances. The measured data is stored in a local small database, analyzed, and displayed to the user. This application is connected to the EMS and receives real-time notifications about suggested changes in electricity and heat consumption based on availability. The notifications are displayed on the home TV. The HEA also records all the activity made by the residents throughout the pilot time. This information will be used to evaluate how effective the pilot is.

The EAA runs on a hand held device and provides a sophisticated interface that tries to attract the residents and should make them aware of the current and historical energy consumption for each appliance at home. For this purpose the research that has been done moves beyond the state of the art in energy feedback technologies by using real-time augmented reality technology on hand-held see-through video to give alerts, interact with the users and allows them to visualize the real-time energy usage of various energy consumption appliances in the home. To do that without tagging the appliances, a special real-time computer vision environment has been created. It runs novel methods for objects recognition specially designed for identifying several target appliances within people’s homes.

This method also enables the augmentation of 2D and 3D graphical objects on the hand held display by overlaying text and figures over the images of the appliances. This provides a natural and clear view of real time information without the need to go through menus or access websites. The information includes notifications on the current status of current energy availability that are provided by the EMS. The augmented reality interface can also provide suggestions for actions that can be carried out by the resident for each appliance. The effectiveness of this novel approach will be tested during the end user pilots later on.

Figure 4 below shows the features of the augmented reality interface in action. Firstly the microwave, which has been captured by the camera of the mobile phone carried by the user, has been correctly identified from the picture. Secondly the background IDEAS software has detected a message from the EPN that the renewable energy supply will be low from 10am to 2pm. This is shown to the user in the top white text area.

Finally the software has combined this information with the fact that microwaves have high peak energy consumption and has produced the request in yellow text that the user might wish to not use their microwave during the period of low availability of renewable energy. Since such messages will be associated also with other home appliances, it is hoped that people’s usage of energy will be shaped to coincide with periods of high availability of renewable energy, thus making it much easier for the EPN to operate in an energy positive manner.

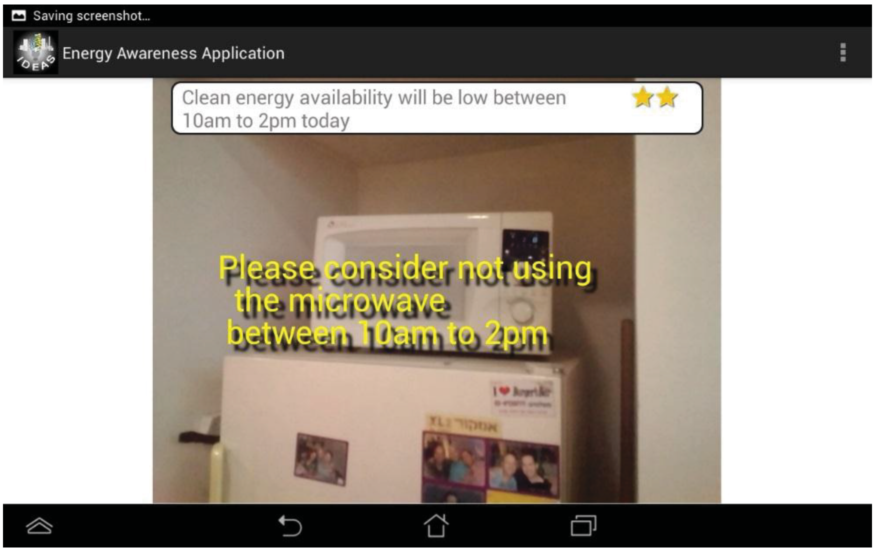

Fig. 4: Energy Awareness Application

Large screens Interface

The objectives of large screens interface applications are to educate residents and/or occupants about energy efficiency of their surrounding environment and to provide and inform them about the impact they have on their own neighborhood. These display the big picture of the neighborhood and can be zoomed in at the neighborhood detail level. These interfaces will display the energy consumption of the whole site as well as the energy consumption of individual buildings. They will show nearly real-time consumption as well as historical data. In order to attract residents/occupants, some alerts, tips and a quiz are also proposed to warn the users of non-sustainable behavior.

The design goals of these interfaces are the following:

- Friendly and intuitive graphic interface
- Encouraging the use of the application
- Application can proceed independently a predefined scenario

As it's not possible to use a tactile screen at the French pilot site, the interfaces there will be implemented as a slide show, mainly focusing on the dynamic data and attractive content. Through a QR code / link displayed on the large screens, the building occupants (students, visitors, etc.) can easily access the full content of the interfaces through any web browser and at any time.
In order to display local information, the application interacts with the EMS. The architecture schema showing these interactions is given in Figure 5.

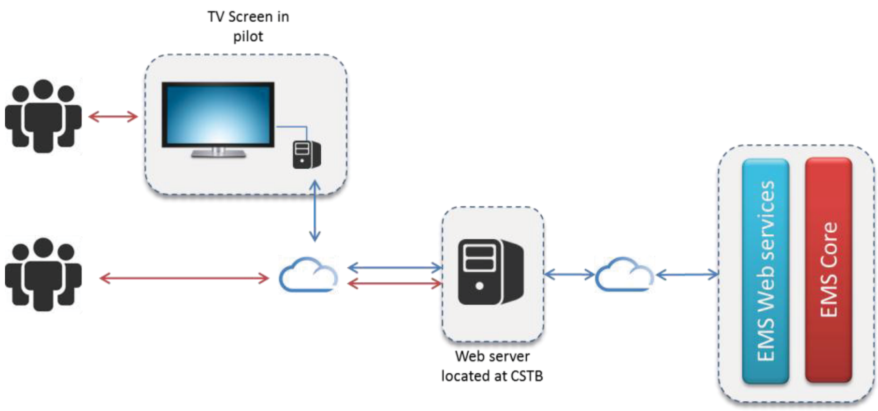

Fig. 5: Interaction of user interfaces with EMS, a Web server and users

A web server hosting the large screens interface application is located offsite at the premises of Centre Scientifique et Technique du Bâtiment (CSTB) in France. It is developed using Ruby and communicates with the EMS through web services to retrieve local data from the pilots. The large screens are installed at strategic locations at the Finnish and French pilot sites. A mini Android computer is connected to each large screen at the pilot sites: it runs the application through a simple web browser and displays it on the screen. Users can also access the application at anytime and anywhere through their personal devices (e.g. tablets, PC, etc.), using a simple web browser. Depending on the pilot site, the content of the large screens interface is available in Swedish, Finnish, English and French. Some screenshots of the large screen interfaces are given in the following figures.

Fig. 6: Finnish context - Large screens application

Fig. 7: Electrical consumption - Large screens application

EPNSP Interfaces

The EPNSP user interfaces (1.10 and 2.1 in Figures 2 & 3 above) are hosted by the IBM® WebSphere Portal embedded by the Intelligent Operations Center ® (IBM® IOC) as part of the EMS. This platform enables modular and flexible application development for these interfaces. They are composed of several screens of text information, many different types of graphs and views used to display data generated by simulation and prediction models and actual data stored inside the EMS data repository.

The main view of the EPNSP interface is a manager dashboard (Figure 8) which summarize most relevant data in real time, for example the current (simulated) energy production in the site, the site energy consumption, the current weather, etc.

The user interfaces retrieve data from the EMS repository using the REST API and they are also connected to the IOC KPI engine (internal feature to the IOC framework) used to calculate different KPIs regarding the performance of the site (see Grilli et al 2014 for more details). The use of the REST API enables lightweight technologies to be used in the client side which give to the EMS interfaces more flexibility and a better user experience. The user interfaces make an extensive use of the Dojo framework (Dojo), an industrial level JavaScript framework partly developed by IBM. The EPNSP User interfaces adopt the same generic structure for each of the pilot sites:

- A login screen
- A site view (3D for Bordeaux, GIS for Porvoo) from which you get detailed views (per building)
- A site level dashboard
- Multiple charts / graphs showing detailed data (historical data, predictions).

Some of the EPNSP user interfaces screenshots are given in Figure 8 and Figure 9:

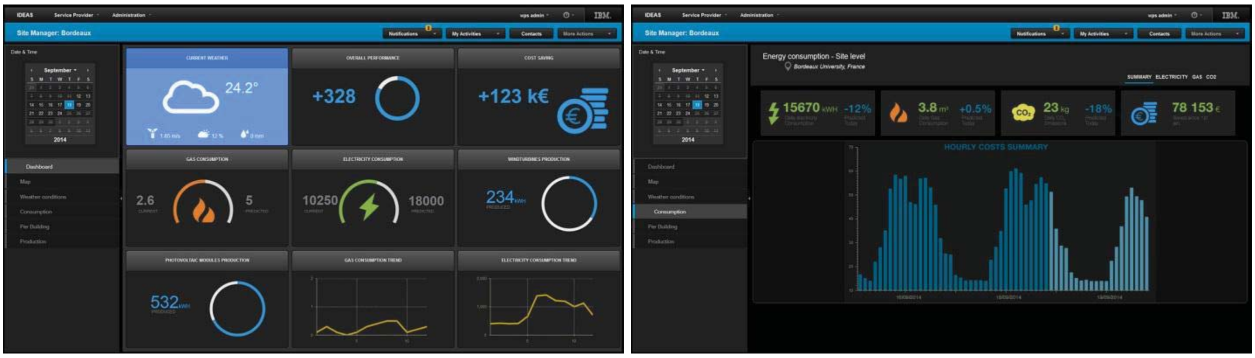

Fig. 8: Dashboard (left) and Energy Consumption of Bordeaux site (right) for Bordeaux Site Manager

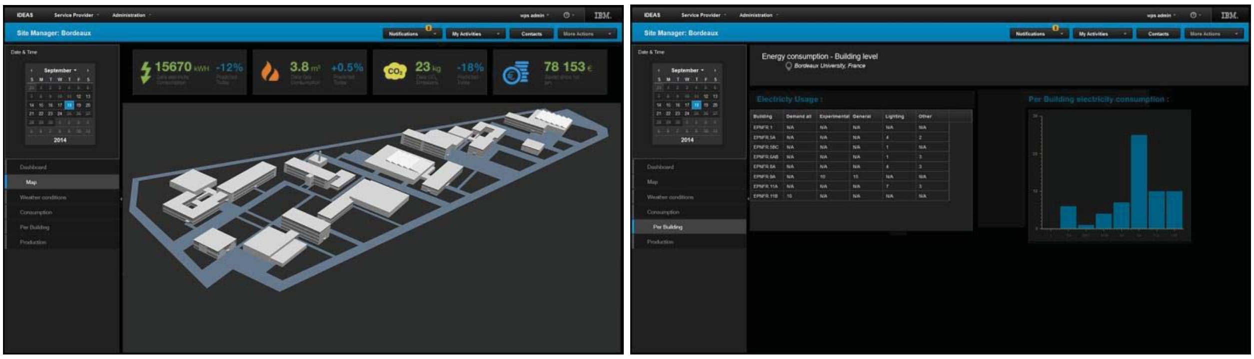

Fig. 9: Bordeaux Site Map (left) and Energy Consumption per building of Bordeaux site (right) for Bordeaux Site Manager

IUT Bordeaux 3D virtual space

The IDEAS project shared 3D virtual space is used to demonstrate the Energy-Positive Neighborhoods (EPN) concepts to remote visitors. The idea is to provide remote visitors with a virtual venue to learn about the IDEAS project, an immersive rich collaborative environment without the need to actually visit the project pilot site. A unique aspect of the virtual environment is the incorporation of simulated energy production and storage elements into the neighborhood representation that do not exist in the real sites, and to show how these are integrated into the intelligent energy management that is developed as part of the IDEAS project.

The environment attempts to be “realistic” in order to involve the students as much as possible. The shared 3D virtual space replicates a portion of the IUT pilot site in Bordeaux, France. It will enable local IUT employees to host external visitors in (virtual) person and to demonstrate the IDEAS project using the visual and data contexts from the physical IUT site.

The virtual site enables visualization of the site global energy consumptions that is available through the actual measurements equipment installed on the site. It focuses on the Civil Engineering department (Figure 10) which is engaged through its activities in energy management and which is equipped with multiple energy systems from which students can learn.

Fig. 10: Civil Engineering Department building (left) and Interactive mock-up showing the stakes at site level (right)

IUT students can enhance the 3D IUT virtual world with new features and virtual information. This will enable the students to be more involved in the IDEAS project and give them a chance to add extensions as they see fit to meet new requirements and project capabilities.

The tool aims at involving the students and informing them about the stakes related to energy consumption at site level. It also presents some simulated production systems embedded in site, illustrates the positive neighborhood functioning based on a balance-sheet including the real consumptions measured on site and the energy production simulated through virtual systems.

Fig. 11: Room dedicated to the description of energy generation systems (left) and Generation systems simulated for the IUT site - 500m² of PV modules, wind turbines (right)

An interactive mock-up (Figure 10) is present in the Virtual space and explains the stakes at site level. The developed system (will be) connected to the IDEAS energy management system and will show real time energy data of the actual site in the virtual site.

The 3D virtual space includes models of the equipment that is actually installed in IUT for the IDEAS project. In addition, it may include additional equipment that was not actually installed due to budget restrictions for example, energy production (PV panels, wind turbines) and energy storage. Their characteristics and simulation data will be provided by the IDEAS Energy Management System.

Figure 11 (left) is a snapshot of a specific room in the virtual world which is devoted to the description of energy generation systems. This part of the tool could also be used profitably for pedagogical purposes by the teachers enabling a wide dissemination of the energy positive neighborhood process of the site. The generation systems are shown (Figure 11 (right)) with their real time simulated production according to the outdoor conditions.

Another dedicated room shows the management and the different usages of the site with real time data shown on virtual screens the same as the ones which are really installed on site. Illustrations of electrical storage are also shown through a display of electrical vehicles in the site (Figure 12).

Fig. 12: Management and different usages of energy on site (left) and Illustration of electrical storage through electrical vehicles (right)

Finally the visit ends with a virtual round table (Figure 13) where host(s) can discuss any matters arising with the person(s) they have invited into the virtual space.

Fig. 13: Round table concludes the visit

CONCLUSIONS

The incremental rollout and operation of energy positive neighborhoods requires ICT tools for energy awareness and management. User interfaces can play a key role in creating energy awareness in residents and helping EPNSP managers with energy management. In this paper, several user interfaces have been described. These user interfaces have been developed in the context of a collaborative European project involving partners from academia and industry. The effective of these user interfaces will be tested in the demonstration phase at two pilot sites. Future works will include results from the tests of these user interfaces at the two pilot sites and their advantages and limitations.

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Dojo Toolkit. Available at http://dojotoolkit.org/

PART V: BIM & VR IN PLANNING, DESIGN & FACILITY MANAGEMENT

IMPLEMENTATION AND EVALUATION OF A MOBILE AUGMENTED REALITY SYSTEM FOR BUILDING MAINTENANCE[1]

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ABSTRACT: *We implemented a mobile AR system for building maintenance workers based on participatory design of the system requirements. The technical implementation relies on hybrid tracking, combining computer vision tools, sensors and indoors locationing. The application was tested in a pilot case by end-users in field tests, where the users were able to evaluate the system that had been developed based on their own specifications. The results indicate good user acceptance and strong potential for utilizing BIM data and mobile AR solutions in building maintenance work, as well as for other building life cycle applications.*

KEYWORDS: *Augmented reality, BIM, facility management, maintenance, participatory design.*

❖ INTRODUCTION

Building Information Models (BIMs) are a widely accepted tool for planning and construction phases of the building industry. However, the application of BIMs after the building work has been completed has remained low. This is unfortunate, as a lot of the BIM information could also be employed in the building's life cycle applications such as maintenance and repair. In addition to the BIM metadata, the 3D representation of the building can serve as a platform to link various other information, e.g. facility management and building automation systems, as well as maintenance reports, as-built documentation etc.

Augmented Reality (AR), on the other hand, is recognized as a most promising technology to help mobile workers with improved situational awareness (Gheisary and Irizarry 2011), also reducing the workers' need to shift their attention from the work target to external devices or manuals. Recent hardware developments e.g. increased computing power and integrated sensors now enable demanding AR applications on mobile phones and tablets. A new generation of wireless optical see-through data glasses e.g. by Epson and Meta open up new usage paradigms, enabled also by commodity level depth cameras and supported by sophisticated computer vision technology, cf. Google's Project Tango. Several vendors are developing indoor locationing technology that may soon be deployed as generally available infrastructures to help develop wide area AR applications; see (Grizzly Analytics 2014).

The DigiSpaces project was carried out in Finland during 2011-2013, with the goal of producing a mobile AR system to access BIM data for mobile maintenance work. We wanted to provide a proof of concept, first, that such a system would be technically feasible to implement, and just as importantly, that it would be useful for the maintenance workers. The software design was based on participatory design and user centric principles, involving users and experts from a group of industrial partners. The partners were among the leading AEC related companies in Finland: Granlund (building services), Pöyry (engineering), Skanska (construction), Tekla (BIM design), Solibri (BIM verification), and Nokia (mobile devices and location based services).

The first part of the project consisted of user studies, qualifying their ideas and wishes for the mobile system (Kuula et al. 2012). As described in (Kuula et al. 2012), the main methodological approach for the user study was participatory design (PD) combined with basic principles of user centric design (UCD). In this approach, the user is involved as an essential part of the design process and the user centric process begins at the very early stages of the project (ISO 9241-210:2010). One of the main findings was that having just the BIM information available on the mobile device was not always sufficient, but other sources, such as Facility Management System (FMS), would be required in many maintenance tasks as well. Also, the users agreed that besides the AR mode, a Virtual Reality (VR) view to the BIM data would be useful in many applications. These requirements were then taken into account in the final system design, and user tests were designed around the typical use cases proposed by the users.

This paper continues from (Kuula et al. 2012) and covers now the technical implementation of the system, pilot cases and user acceptance. The paper is organized as follows. Section 2 discusses previous work in BIM related mobile AR research. Section 3 recaps the results of our first user studies, leading to system requirements. Section 4 describes the final system architecture and functionality, with a discussion in Section 5 for tracking and locationing

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technologies. Section 6 describes the second round of user studies for technology acceptance, performed in a real world pilot case. Section 7 draws the conclusions and lists some items for future work.

RELATED WORK

The first mobile outdoors AR system was presented by Feiner et al. (1997), with a backpack PC and HMD to view information around the Columbia University campus area. Some years later, the first handheld systems included marker based AR solutions on PDAs (Pasman and Woodward 2003) and on mobile phones (Henrysson and Ollila 2004). Among the next ground breaking steps, one of the first systems combining hybrid computer vision and sensor-based tracking for mobile outdoor applications was presented by Reitmayr and Drummond (2006).

Today, several commercial and even free of charge AR systems for building visualization are available for mobile phones and tablets. Tracking is most typically based on GPS and compass sensors. Mobile AR applications in the AEC field have been studied e.g. by Olsson et al. (2012) for city planning, and also by Woodward and Hakkarainen (2011) for construction time visualization. Accurate 3D tracking technology was introduced to construction sites by Peña-Mora et al. (2010), utilizing 3D point clouds generated from site photos. Our tracking also relies on image based point clouds, furthermore we perform AR on live video instead of still images.

Mobile AR has been applied much more in outdoor applications than indoors, one reason being the limitations of GPS locationing. Among BIM related applications, mobile AR solutions have been practically non-existent until the last couple of years. Remarkable work for mobile AR and maintenance applications has recently been presented by Kahn et al. (2012). They combine various computer vision tools, 3D reconstructions and sensors to provide reliable tracking, offer the choice of client-server or stand-alone solutions on the mobile device, integrate BIM and FMS in their system, provide a user interface with annotations and other feedback, etc. Thus their system is functionally quite similar to ours, in system integration terms probably closer to practical applicability, and comparable in tracking implementation and performance.

Another approach for mobile AR maintenance has been presented by Irizarry et al. (2013). Their InfoSPOT system utilizes BIMs for facility management, based on predefined natural markers in the environment. They include comprehensive user tests in their study, evaluating user acceptance and performance with different modalities of the system. The main differences compared to our work, besides technical e.g. tracking issues, are that our user studies were performed in two stages following the PD and UCD priciples. In conclusion, our user studies serve to verify the positive user evaluation results of Irizarry et al. (2013).

Commercial activity in the mobile AR maintenance field has recently been presented by NAVVIS, a spin-out company of the Technical University of Munchen (NAVVIS 2014). Similarly to us, they use 3D point clouds of the interiors as basis for camera tracking. We use an autonomous robot for location fingerprinting and point cloud acquisition, instead of their manually operated trolley. The German company Augmensys (2014) carries out related work with mobile AR and industrial plant asset management. Among further players, some of Bentley's activities in the AR / AEC field are reported by Cote et al. (2013).

To summarize, our work has advanced in parallel with other research groups that have been working in the same field since our first report (Kuula et al. 2012). The main new contributions of our work are: first engaging users in the design phase of the application; this leading to a set of features and functionality specifically designed for the maintenance application; an implementation including accurate real-time tracking based on several 3D point clouds; and finally, user tests with a real world pilot case verifying the user acceptance of the proposed solution.

SYSTEM REQUIREMENTS

Our first round of user studies started at the end of 2011. First, workshops were carried out with experts from all the participating companies. Next, personnel working in maintenance and construction from three companies (Granlund, Skanska and Pöyry) took part in four group interviews in January-February 2012. Altogether, 12 people participated in the interviews, 2-4 persons in each interview. The interviews followed the user centric design and participatory design principles, as described in (Kuula et al. 2012). The aim of the interviews was to collect user ideas to support and guide the technical development of the mobile AR maintenance application.

Altogether, 43 ideas were collected and listed in the group interviews. After some filtering to reject overlapping ideas and those with no locationing need, 29 relevant ideas remained on the list. The ideas were categorized based on two criteria: 1) the data source(s) relating to the idea, and 2) the role of AR in the idea. Regarding the data sources, only 4 ideas included BIM as the only data source, 6 ideas did not include BIM at all, 14 ideas included BIM and some other data source, and 5 ideas included BIM and several data sources; see Figure 1. The other data sources included building automation system, facility management system, and building service books.

The role of AR was classified in four categories: 1) AR in major role; 2) AR in supporting role; 3) tracking of the

target device, but no AR view required; 4) locationing of the building area (no AR). Based on this analysis, 18 ideas with BIM as data source included AR in a major or supporting role. Thus, 62% of all 29 relevant ideas supported our hypothesis of combining BIM with a mobile AR view being useful to the maintenance worker.
Experts from the participating three companies were then asked to prioritize these ideas on a scale from 1 (most important) to 3 (less important). As result, 16 ideas had an average priority value less than 2 and were chosen for more detailed study. Out of these, as many as 13 ideas had AR in a major role. The full list of the top 16 priority ideas is provided in (Kuula et al. 2012). Figure 1 shows the categorization of these ideas in a single picture

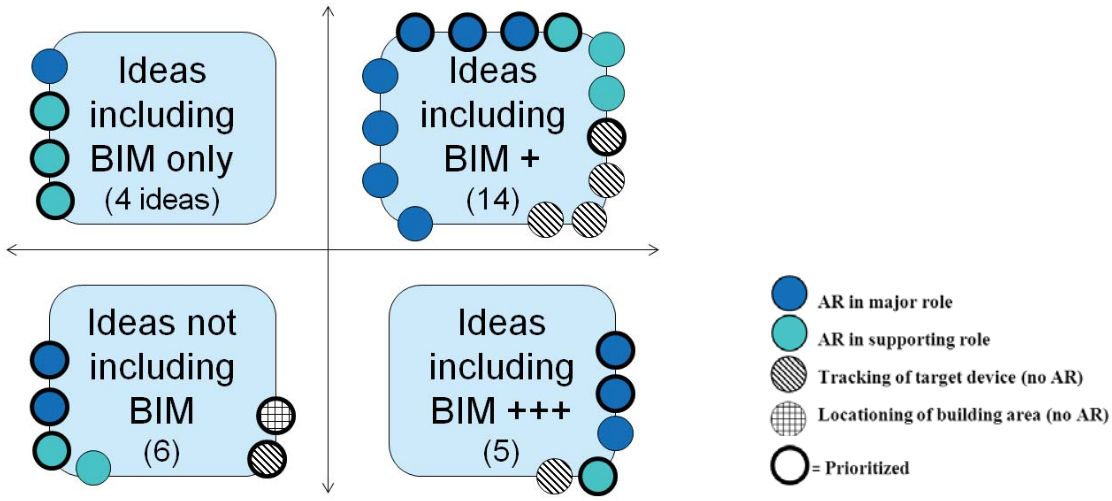

Fig. 1: Categorization of ideas based on data source, role of AR and company priorities. BIM+ denotes ideas including BIM and one other data source, and BIM+++ ideas with several other data sources. (Kuula et al. 2012).
In the last step of the study, we categorized the 16 top priority ideas in a further three categories, according to their relevance to our project. Six ideas were identified as having both AR in major (or supporting) role, and simultaneously involving BIM (and possibly one additional data source). These ideas were:

1. BIM based fault diagnosis
2. Viewing the zone affected by a faulty device in 3D
3. Mobile route guidance for walking inside the building
4. Building performance and related problem monitoring in 3D
5. Viewing of target spaces through different user profiles
6. How to send information to necessary parties involved

These six top priority ideas were chosen for implementation in the mobile AR system, and as use cases for our next round of user studies. The ideas 1–3 included BIM as the only data source, thus they were fundamentally of highest priority from the perspectives of this study. For additional data sources, we implemented some facility management system functionality, though based only on simulations and not linked to any real FMS system. Also, some other simplifications had to be made due to a limited project budget, covering a total of 28 person months for all the work.

MODULES AND FUNCTIONALITY

The DigiSpaces software architecture contains four software modules: 1) DS_BIM_Studio, 2) DS_AR_Studio, 3) DS_Browser and 4) point cloud generation tools; see the system diagram in (Kuula et al. 2012). In this Section we describe the final implementation and main features of the first three modules; tracking solutions and point cloud generation tools are discussed separately in Section 5. The first generation of these three modules was developed in the AR4BC project (Hakkarainen et al. 2009, Woodward and Hakkarainen 2011), where a similar mobile outdoor AR system architecture was implemented for architectural planning and construction visualization. In the DigiSpaces project the software modules were adopted for building maintenance tasks, now using a completely rewritten set of tracking technologies.

BIM import and interaction

DS_BIM_Studio is a Windows desktop application used at the office, to import, visualize and interact with the building's 3D model and related data.
The system supports IFC and OSG compatible 3D formats. Besides BIM metadata, the application allows importing XML data from various other data sources and mapping the information to the BIM's elements. The external sources can be e.g. facility management system or service book. The mapping is achieved by selecting and combining data from XML files and attaching the data to the corresponding BIM elements. The system can also be used for updating BIM's part data/name in case the information is not complete, by adding part IDs etc.
The application also displays user feedback that has been collected from the site. In the current prototype, this feature was implemented only for reports through the FMS service requests. Our first implementation did not support free-form reports or e.g photos taken by users.

AR and tracking content

DS_AR_Studio is a Windows desktop application, used at the office for the AR and 3D tracking content authoring e.g. defining the geometric relations of the site's floor layout, 3D models and point clouds.
The first step for creating an AR setup for the site is opening the site's floor plan. The floor plan can be basically any common image file format (jpeg, tiff etc.). The 3D model, or part of it e.g. 1st floor, is placed on the floor plan interactively by defining at least three point correspondences between the floor plan and the 3D model. Further model parts can then be imported and aligned with the previously defined parts.
The final step is to load and align the point clouds with the 3D model (BIM). The system allows importing several point clouds and (sub) models from the site. In the current implementation the alignment of point clouds is done interactively; this step could be avoided e.g. by using markers at predefined locations when producing the point clouds. Section 5 discusses further automated methods, i.e. using a locationing robot for the point cloud alignment.
After the alignment of the floor plan, 3D models and point clouds, including BIM metadata and external links from the DS_BIM_Studio, the application content is completely defined, and ready to be exported to the mobile application as XML descriptions.

Mobile AR application

DS_Browser is the mobile AR maintenance application for the end user on the site. DS_Browser handles the AR tracking, visualizes the BIM in AR and VR views, visualizes the warnings and alarms from the FMS or maintenance reports and allows the user to react to them. The current implementation is done for Windows tablets. While we did not have real access to the FMS, we simulated the connection by creating a local database for certain scenarios. These scenarios were built based on the end user interviews at the start of the project. We did not implement all the proposed features and scenarios, but concentrated on the cases chosen for piloting the system with the users.
Among the basic features, DS_Browser can be used to visualize the site's floor plan. The primary use of the floor plan is to allow the user to navigate to the right room or section of the building. When at the target location, the user downloads the corresponding "DS project" from the server to the mobile device. This project file contains the 3D model of the site, point cloud and the FMS information of the location. In the current prototype, loading of the correct project is the user's responsibility; this could of course be automated based on the locationing data.
As the user selects the AR view and points the camera to the target, the BIM is visualized partly transparent in the right position and orientation. This gives an illusion that the BIM is merged with the real, existing building. The user may move and pan with the device (camera) to browse the environment and the 3D tracking holds the model in right position and orientation. The user may also press pause and "freeze" the live augmented view. This makes interaction with the system easier than having to hold the device towards the target, when writing the report etc.
The user is able to get model information by browsing the model's part list. The selected part is highlighted in the AR view. The user is also able to select objects of interest from the AR view by clicking the BIM part. The part is highlighted in the view and in the part list, and additional part information is shown to the user. The user is able to add feedback on the part, e.g. mark a maintenance procedure being done or pending for further action.
Visualization of the BIM can be restricted to certain parts only, and parts can be removed from the AR view by clicking on them. The system allows the BIM parts to be visualized independently or in groups. Having access to part groups is useful especially when the source of the problem is at a different location than the effect; take for example air conditioning, where the effect may be in the room but the reason is in the air conditioning unit elsewhere (see Figure 2).
If the room or site contains warnings or alarms from the FMS, these are visualized on the AR view with certain

colours (warning – yellow, alarm – red, etc.). The user may click on any part of the BIM or related links to get more information on the parts, remove the parts, take a look "behind the walls", etc. As the user clicks on an alarm, he or she is provided with the alarm report from the FMS. The user may then resolve the alarm or discard it for later inspection.

Besides the AR mode, we implemented the same functionality in a VR view, where the user may inspect the BIM from arbitrary viewing angles and close-ups. This requirement was brought to us by the users in the first part of the user studies. Naturally, the application also allows browsing the error and warning list without any visualization; this may help the end user to react to the errors without searching for them, especially in familiar cases.

TRACKING AND LOCATIONING

Accurate indoor positioning and 3D tracking is required for the application to display BIM and other maintenance information correctly aligned with the real environment. We tested several approaches and finally selected a set of them for the pilot experiments:

- *Point cloud tracking*. Our primary tracking solution is to use pre-computed point clouds along with estimated keyframe positions for visual tracking. In a pre-processing step, a sparse 3D reconstruction of the area is created using 30-100 photos (keyframes) from each target area. The point clouds are created using the open source software Bundler (Snavely et. al. 2006). During real time tracking, the system finds point correspondences between the video frames and point cloud keyframes. The point correspondences are used for automatic tracking initialization and then to track the camera movements in all six degrees of freedom. See further details of the implementation and performance below.
- *Model based tracking*. Initially we planned on using the available BIM models instead of reconstructed 3D point clouds for tracking. However, in the end we were not able to produce an implementation that would be usable in pilots with this technology. The main challenge was that even detailed BIM models did not contain enough visible features compared with the real life video view.
- *Inertial Measurement Unit (IMU)*. We use an IMU for assisting point cloud tracking in fast camera rotations and in cases where the user turns to look at an area without existing point cloud data. The system automatically notices when point cloud tracking does not give a valid result and switches to use the IMU instead. Along with point cloud tracking, this was also used in the pilot system implementation.
- *Compass*. We also experimented with using the compass to aid with the tracking initialization, however the indoor compass accuracy did not provide much help for this purpose and was not used in the pilots.
- *WLAN fingerprint based positioning*. We integrated to the system WLAN fingerprint based positioning where a pre-computed map of WLAN signal strengths was used to estimate the user position on the floorplan. This information was used for navigation purposes in some tests, but was not used in the final pilots as the accuracy did not seem to be useful enough in the planned testing environment.
- *High Accuracy Indoor Positioning (HAIP).* The HAIP positioning technology was originally developed by Nokia and commercialized by the company Quuppa (Quuppa 2014). The method uses HAIP locator devices, installed e.g. on ceilings, that locate the bluetooth signal direction of special HAIP tags. In our tests HAIP achieved good 1 meter accuracy. HAIP positioning was integrated into the tracking system, but it was not used in the pilot as we covered only a very limited area with our HAIP locators available.
- *Mapping robot.* A special challenge with the point cloud tracking approach is collecting the reference material (images) from the environment. We developed in parallel EIT ICT Labs projects an autonomous robot to collect the tracking data. The robot collects the data needed for WLAN fingerprint based positioning, as well as images for creating the point clouds for visual tracking. Our robot has good inherent positioning based on various sensors, e.g. odometry and Kinect. As each image is tagged with this information, we could align the tracking point clouds semi-automatically with the BIM model. Also, we implemented a method to automatically download available point clouds from the server only using visual information from the mobile device. See video (VTT 2013b) for the mapping robot in action.

Our point cloud tracking uses similar approach as Fraunhofer (Kahn et al. 2012), although our implementations are completely independent. In brief summary, our tracker first finds feature matches between the current image frame and point cloud key frames using ORB keypoint detector and BRIEF descriptor. Based on the feature matches, 3D coordinates from the point cloud are associated with 2D points in the current frame and calculate the initial pose for the camera. After initialization, the feature points on the image plane are tracked using optical flow estimation with the Lucas-Kanade method. For each frame, the pose is optimized with the updated data using Levenberg-Marquardt with M-estimators to make it robust for outliers. To allow free movement around the whole target area, features that go out from the frame or do not match the current pose estimation are dropped from the tracker and new features are added from the point cloud dynamically.

With an “old” ACER Iconia Tab W500 with an AMD C-60 1.0 GHz processor that was used in the pilots, our point cloud tracker was about 15 fps as a separate process. The complete AR loop including video capture, IMU support and rendering reached some 10 fps. On a more powerful Dell Latitude E6530 laptop with an Intel 2.60 GHz processor, the tracking speed is theoretically (with a fast enough camera) over 100 fps, cf. video (VTT 2013a).

TECHNOLOGY ACCEPTANCE

Pilot case

VTT’s office building, “Digitalo“, located in Espoo Finland was chosen as the location of our pilot case for the second round of user tests. Other possible cases were also considered,, but access to the updated BIMs of these buildings turned out difficult e.g. for proprietary reasons. Digitalo was finally chosen because of its convenient location for researchers and because of access to accurate BIM models. Two separate user tests with different participants were conducted on the premises of Digitalo in October 2013, both including two imaginary problem situations typical for maintenance work as derived from the ideas of the first round of user studies in 2012.

User groups

Two groups of users participated in the test. The participants of the first test group were maintenance workers of Digitalo and VTT’s facility coordinators, 5 persons altogether. These two worker groups collaborate closely together even on a daily basis and represented the planned end users of the mobile system. The participants of the second test group were named by partner companies Granlund and Skanska representing expert and manager level workers in building management and construction, 4 persons altogether. Furthermore, the system designer from VTT was present in both tests. The tests were led by VTT’s researcher of user-centred design. Following the principles of participatory design, different stakeholders were asked to participate in collaboration including face-to-face interaction and emphasizing working in groups (Friedrich 2013).

Implementation of the user test

The user test consisted of two imaginary problem situations which were realised in two different spaces of Digitalo. These cases were based on the highly prioritized features in the previous round of user studies, including fault diagnosis and finding the malfunction area using BIM data. The cases are outlined in Table 1.

	Space	**Problem**	**Tasks**
Case 1	Lobby	Feeling of draught in the lobby caused by air conditioning	Find the malfunction area Find the host device Read the data from the host device Solve the problem; write a report
Case 2	Meeting room	Two alarms and one warning in the room	Find alarm 1: broken camera Find alarm 2: broken thermostat Find warning: lamp of projector must be changed soon Solve the problems; write reports

Table 1. Use cases.

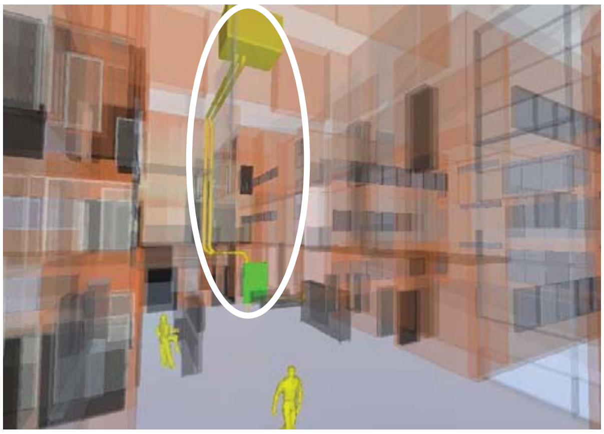

Fig 2: Left: Mobile user browsing the problem in AR view. Right: BIM with malfunction device highlighted.

Figure 2 shows the malfunction area of Case 1 highlighted in the BIM, and the mobile user finding the cause of problem using the mobile AR application. Figure 3 shows the mobile user inspecting warnings and alarms of Case 2. The pilot cases are also demonstrated live on video (VTT 2013a).

Both tests with groups 1 and 2 included the same cases. At the beginning of the test, a short introduction to the project and the mobile AR system was given to the participants. Then, the participants were asked to accomplish the case tasks with the system. The system designer gave instructions when needed and explained how the system works.

After the actual test phase, a group interview was conducted by the researcher. From the Technology Acceptance Model (TAM), the concepts of *perceived ease of use* and *perceived usefulness* (Davis 1989) were included in the interview questions. The final interview structure consisted of the following themes:

1. Overall evaluation: advantages and disadvantages of the system
2. Ease of use of the system
3. Usefulness of the system
4. Attitude towards using the system
5. Other experiences of utilising mobile technology for work purposes

Additionally, an email questionnaire was sent after a couple of days to the participants of both test groups. Eight out of nine (N=8) participants answered the questionnaire. The questionnaire partly followed the themes of the interview including statements on *usefulness and ease of use*. Additional specific statements related to *BIM and AR relevance to the application* were included. The scale used in the questionnaire was 1–7, in which 1 = completely disagree, 7 = completely agree. The statements are separately presented in Section 6.4. The results of the user study are based both on analysis of the interviews and questionnaires.

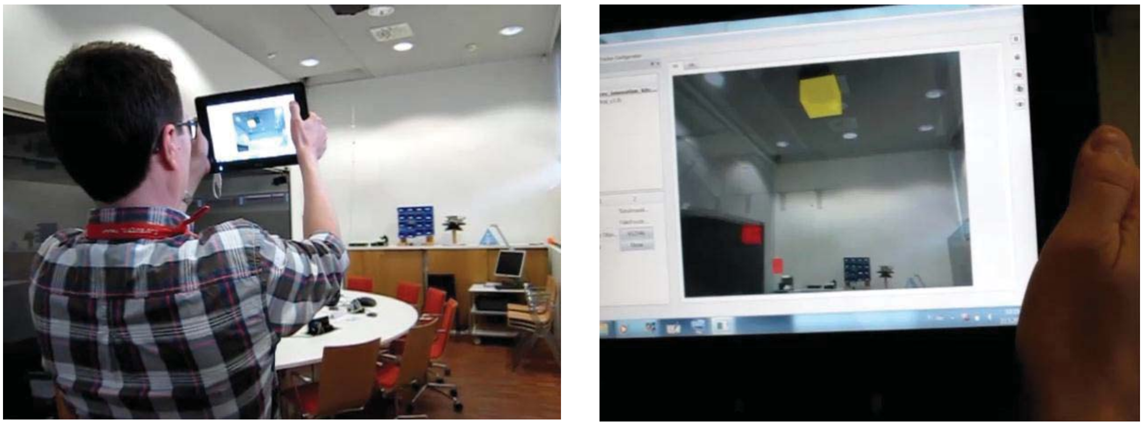

Fig. 3: Left: Mobile user finding warnings and alarms in a room. Right: Alerts highlighted in AR view.

User test results

According to the results of the interviews and the questionnaire, the participants' attitude towards the system and its potential was generally very positive. The average of the questionnaire statement *The tablet system would be useful in practical work* was **6,50** (7 = completely agree), and the average of the statement *It is worthwhile to develop the system further into a completed product* was **6,63**.

In both user groups it was stated that the system would be useful as an indoor navigation tool for the maintenance worker and it would especially help when arriving into a new and unknown location. The second significant benefit would be that with the tablet it would be possible to have all the necessary documentation and technical material needed for the maintenance work available on the spot.

In group 1 (maintenance workers, facility coordinators), the usefulness of the system in electrical repairs was emphasized, since the switchboard of the device could be situated in a completely different place than the actual device. Secondly, the possibility to predict forthcoming repair and maintenance tasks with the help of visual cues provided by the system was considered useful (cf. Table 1: "warning" in user test case 2).

In group 2 (building management and construction), it was generally agreed that the AR view would make it possible to notice more effectively the devices that affect the given malfunction. The VR mode was also mentioned as an illustrative feature.
Specific questions relating to the usefulness of AR-visualisation and to the utilisation of BIM models were included in the questionnaire. The average of the statement *AR visualisation of the targets of maintenance would help in practical work* was **6,0**, and the average of the statement *BIM model contents of the building on a mobile device would help in practical work* was **6,38**.

System usability and suitability for current work

The questionnaire's usability-related statement *Use of the current version of the tablet system was easy* gave an average of **4,75**. It should be noted that the system was still a prototype and not finalized for everyday work. The following usability aspects were stated in the interviews:

- The amount of buttons should be limited and the buttons should be large enough
- One should be able to customize the view based on user needs or profile
- Both right- and left-handed version of the system are needed
- The tablet should have a protective cover and a handle
- The "pause"-button for freezing the display view was considered as an especially good feature

As a technology, the system was said to be well suited for current daily activities in both groups. The maintenance workers and facility coordinators (group 1) were not completely happy with their current working tools and devices and expressed their wish to get tablets as devices for work. The maintenance workers have a number of locations to visit and they are constantly on the move, thus their tools should support mobile work.
Compared with other portable devices, laptop computers were considered to be bulky and inconvenient to use, while the screen of a smart phone is simply too small. However, the advantage of a phone is that one is always carrying it, unlike the tablet.
In both test groups, narrow and dark tunnels were considered problematic when using the system, as well as changing conditions in terms of e.g. humidity and temperature. Durability and battery life of the tablet were also matters of discussion.

User remarks for further development

A number of additional ideas and remarks for further development of the system were given in the groups, describing different viewpoints of the use and utility of the system. Some remarks concerned functionality that we had intended to implement, but which had to be dropped due to limited resources: for example, sending and storing photos and comments of arbitrary targets; saving the maintenance history of the target equipment in the backend system; and combining building service book with the mobile AR system. Improvements were also proposed on the style and amount of BIM elements to be visualized for different tasks. Among further ideas, it was proposed that in a large space, the system should give a hint e.g. alarm sound about the maintenance need and direction of the alarms.

CONCLUSIONS AND FUTURE WORK

In this paper, we have described the implementation of a mobile AR system for building maintenance workers, based on earlier user studies to define the system requirements, and completed with a second round of studies for user acceptance. Several results from the first round of studies were taken into account in the final (prototype) implementation.
Among the most important findings, it was obvious from the user comments that other data sources such as FMS should be integrated into the system besides BIM. The system implementation included several other features that were appreciated by the users, e.g. VR view for remote inspections, and "freeze view" to enable keyboard input and other interaction. The available resources did not allow us to implement all the features proposed by the users. Nevertheless, the second round of user tests showed very positive results for user acceptance of the prototype application, thus validating our original research hypothesis (Kuula et al. 2012) as well as verifying the findings by other researchers (Irizarry et al. 2013).
The very positive user evaluation results were most likely affected by the idea that the tablets would be generally useful in everyday maintenance work, not just limited to functionality of the DigiSpaces mobile AR application. The assumption that tablets create better working conditions might have affected the evaluation (possible Hawthorne effect especially in user group 1). However, during the group interviews also negative aspects were mentioned and the interviewees were encouraged to give truthful answers

On the technical side, our implementation offers fast and accurate 3D tracking functionality based on point cloud reconstructions, complemented with sensor based tracking to achieve generality and robustness. Our pilot experiments were executed in a limited area of the building (two rooms), but our discussion extends to covering wider areas e.g. whole buildings by automatic point cloud acquisition methods using a locationing robot. Even if building wide locationing infrastructures (e.g. WLAN or HAIP) are not available, we have demonstrated how to provide locationing solutions and dynamic downloading of tracking data using only computer vision based tools.
In future work, our most important task will be to integrate the system to real world FMS and other production systems already in place for building maintenance work. On the system implementation side, the user interface needs to be better adapted for mobile use. In particular, when considering integration with new generation data glasses, the system will most likely require more work on HCI aspects and a focus on a subset of key features.
Finally, we hope that BIM practices will be developed to better serve building life-cycle applications, besides their current use for planning and construction. Much of the current BIM information is actually not required after the construction phase, and it should be made easy to extract the relevant components and level-of-detail for having BIMs serve as a living document and data repository for building life cycle management.

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EVALUATION OF IFC AND COBIE AS DATA SOURCES FOR ASSET REGISTER CREATION AND SERVICE LIFE PLANNING[1]

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ABSTRACT: *Operation and Maintenance costs in buildings represent a large part of the total building lifecycle cost. However, project delivery methods in the Architectural, Engineering Construction (AEC) industry are often focused on capital delivery and associated costs, which occur prior to the building handover to owners and occupiers. With the emergence of data specifications such as COBie (Construction and Operation Building information exchange) and the IFC (Industry Foundation Classes) open standard, there has been an increased interest in developing approaches that integrate building operation with the capital delivery phases. In this context, this research aims to assess how open BIM standards (i.e. IFC) and data specifications (i.e. COBie) can support information requirements of facility managers. A literature review of current studies on Building Information Modelling (BIM) for facilities management (FM) in general, and on IFC and COBie applications in FM in particular was conducted. Based on the results from the literature review, a use case was developed according to the Information Delivery Manual (IDM) methodology, in order to assess the applicability of IFC and COBie as sources of information for asset register creation and service life planning. The results from this use case highlighted shortcomings in IFC/COBie standards and commercially available tools and suggested improvements. In future work, the proposed research approach will be applied on a wider number of use cases in order to develop a decision support system that utilises asset information from BIM to enable lifecycle cost planning during the use phase of buildings.*

KEYWORDS: *BIM, Facilities Management, Asset Register, IFC, COBie, IDM*

❖ INTRODUCTION

Construction projects are often driven by the consideration of time, cost and safety constraints during the capital delivery phases of projects. When making design decisions, owners and project stakeholders are often focused on initial construction costs without much consideration for operation and maintenance costs, which could amount to over half of the total building lifecycle costs (Becerik-Gerber et al. 2012).

Maintenance can be defined, according to ISO as the “Combination of all technical and associated administrative actions during service life to retain a building or its parts in a state in which it can perform its required functions.” (ISO 2011, p.2). In the case of high-use buildings, such as public, healthcare, education, and commercial buildings, maintenance operations are frequent during the use phase of their lifecycle, which can last for several decades. It is therefore essential to plan for maintenance from the inception phase of projects considering owners’ requirements for the building.

Building maintenance activities are multidisciplinary efforts with extensive information requirements. Maintenance efforts during the occupancy and post-occupancy stages of the building lifecycle should be accounted for from project inception and checked throughout lifecycle phases in order to maximize the use of buildings, and minimize risk and maintenance costs (BSRIA 2009). The Building Information Modelling (BIM) methodology aims to provide means to support the seamless exchange of information throughout the lifecycle of buildings through the integration of technologies, while supporting industry stakeholders’ processes. The use of BIM in a whole lifecycle approach can provide the support of the needed information for asset maintenance planning and execution, provided that information is kept in an organized management system (CIC 2012). BIM can contribute to facilities management both as an information source and as a repository to support the planning and management of building maintenance activities in both new and existing buildings (Volk et al. 2014).

The need for the provision of structured data for asset information models has been recognized in PAS1192-3:2014, which specifies an information management methodology for the operational phase of building assets based on

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open BIM standards IFC and COBie (BSI 2014a). Also, standardisation efforts are proposing the use of open BIM standards IFC and COBie for service life planning – ISO 15686-4:2014 (ISO 2014) - and lifecycle costing during the maintenance phase of buildings – BS 8544:2013 (BSI 2013).

HM Government's BIM Programme has mandated the use of level 2 BIM (file-based collaboration and library management) on all centrally procured Government projects by 2016, and has adopted COBie as the selected format for the information exchange between project capital delivery phases and the operational phase (BSI 2014a). While recent research has identified requirements to support building maintenance tasks with BIM (Becerik-Gerber et al. 2012, CIC 2012, Motamedi et al. 2014), it is necessary to evaluate how existing tools and current open BIM standards IFC and COBie can support these requirements and inform decision making for maintenance from the early stages of project development. The role of construction clients in the definition and continuous checking of detailed requirements also needs to be accounted for (BSRIA 2009). In this context, this paper is focusing on research to a) determine methods for clients' maintenance requirements capture into BIM and b) evaluate IFC/COBie support for information requirements to carry out maintenance planning and execution tasks.

The research question that drives this study is:

How to support and enable decision making for owners and facility managers during the use phase of buildings using an asset information modelling methodology based on open BIM standards (IFC/COBie)?

RESEARCH METHODOLOGY

The main objective of this research is to support the decision-making processes in facility management tasks considering the planning and optimization of lifecycle costs during the use phase of buildings.

In order to fulfil this objective, this research aims to assess the suitability of open BIM standards (IFC/COBie) and building modelling tools to capture and integrate the information from BIM into FM, in order to support proactive asset planning and maintenance methodologies in buildings. For this purpose, a literature review has been carried out focusing on current methodologies and research for FM, and how they can be supported by BIM. Based on findings from the literature, an analysis is carried out to evaluate how BIM can provide the required information for asset registers in order to support owners' requirements in facility management tasks. A use case is developed based on the IDM methodology with the goal of producing COBie data drops according to specific owners' requirements. A discussion is carried out focusing on the results of the analysis and use case development, and improvements are proposed.

LITERATURE REVIEW

BIM and FM

Facilities management can be defined as an integrated approach to operating, maintaining, improving and adapting buildings and infrastructure of an organization in order to support its primary objectives (Atkin, Brooks 2009). FM constitutes an extensive field encompassing multidisciplinary independent disciplines whose overall purpose is to maximize building functions while ensuring occupants wellbeing (Atkin, Brooks 2009, Becerik-Gerber et al. 2012). FM functions hold extensive information requirements from various fields in order to fulfil their purpose. Currently, information is mostly organized and maintained in dispersed information systems (CMMS, EDMS, EMS, and BAS), which require various inputs. Information typically has to be introduced several times and is not synchronized between systems, resulting in error-prone processes (Becerik-Gerber et al. 2012). Equally significant is the lack of use of standards which can define what information is needed for specific FM tasks. There is a need for open systems and standardised data libraries that can be utilised by any FM system (BIFM 2012), however, in existing buildings, FM legacy systems which do not support open BIM standards may be used during the next decades (Kelly et al. 2013).

BIM allows the management and integration of the information needed for FM through the use of open standards, providing a single source of accurate and up to date information. The potential of BIM for FM was realized during early development of the IFC standard. With the aim of improving the facilities management practice, early developments of BIM for FM focused on standardized open data models in order to enable information sharing among computer applications (Yu et al. 2000). In this study the authors proposed a data model for FM - Facilities management core model (FMC) – along with mapping between IFC and FMC.

Open BIM standards such as IFC (registered with ISO as ISO16739 (buildingSMART 2014a)) and COBie are continuously being developed by buildingSMART with input from the AEC industry, in order to support information exchanges according to the industry's business processes. These standards allow models to be structured in a universal way, allowing owners and their project teams to define attributes unambiguously, enabling product data to be exchanged between designers, suppliers, constructors and operators (Atkin, Brooks 2009). The definition of COBie data drops has also been introduced in the UK in order to capture and check client's requirements throughout the lifecycle of buildings. Data drops specify data requirements for key stages of building lifecycle development and are aligned with RIBA Plan of Work stages (Cabinet Office 2012).

In order to support the use BIM for asset maintenance tasks, and to meet the HM Government's BIM Programme target to have all centrally-procured Government projects adopt BIM Level 2 by 2016, the PAS1192-3:2014 specifies an information management methodology for the operational phase of buildings. This specification proposes the use of open standards, IFC and COBie, for the definition of Asset Information Models (AIMs) and for the interface between AIMs and existing enterprise systems (BSI 2014a).

BIM and FM case studies

BIM can support FM functions both for new and existing buildings (Volk et al. 2014). One example of the support of BIM for FM in an existing building is the Sydney Opera House (CRC 2007). In this project, the Sydney Opera House was modelled specifically for FM purposes and the IFC standard was evaluated regarding its support for FM functions. This project demonstrates the possibilities of BIM for FM and highlights changes needed in current work processes to support the proposed methodology. The project also highlights the lack of support of the IFC standard from FM tools. A more recent application of BIM for FM can be found in the BIM-FM Manchester Town Hall Complex report (Codinhoto et al. 2013). This project aimed to investigate the key issues in migrating from traditional FM to a BIM-based FM system to perform reactive maintenance. The main findings indicate that BIM can facilitate the search for the needed information to perform reactive maintenance tasks, allowing FM managers to perform better diagnosis of reported issues.

The use of BIM for FM allows for the provision of accurate information to inform decision-making processes in building maintenance. Motawa and Almarshawad (2013) have proposed a methodology to support decision-making in building maintenance activities. The authors proposed the combined use of BIM and case-based reasoning to capture and manage knowledge in building information models in order to inform maintenance teams about the history of the building and its components. In order to provide decision support for facility management and maintenance, Shen et al. (2012) have proposed an information integration framework supporting software and hardware applications using agent-based web-services.

The visualization capabilities of BIM and their role in decision making for O&M tasks have also been the focus of recent research. Motamedi et al. (2014) have proposed the integration of CMMS data with BIM in order to use BIM visualization capabilities for failure root cause detection in FM. Fault tree analysis was used to capture knowledge about building systems failures and to provide decision support to FM technicians. In order to capture failure mechanisms the authors proposed the use of IFC model relationships. Rasys et al. (2013) have proposed an information integration framework for the management of civil and oil & gas facilities using Web3D technology for the integration and visualization of assets information in 3D models. Hallberg and Tarandi (2011) have proposed a lifecycle management system for construction assets based on the IFC standard and 4D visualization. The authors state that IFC models constitute a clearer and more efficient source of information when compared to traditional database solutions. However, according to the authors, IFC2x3 does not support lifecycle management during the maintenance phase and needs further development in order to support all lifecycle management system functions. The use of spatial relationships represented in BIM for visualization and analyses of facilities data has also been considered for the planning of maintenance activities and repair works in buildings (Akcamete et al. 2010). While there have been many research efforts in BIM for FM, industry-wide applications are still lacking. Standardization efforts such as IFC and COBie can contribute to the organization of information for FM tasks. The definition of COBie data drops specifies which information in the COBie spreadsheet should be filled out during each stage of project development. However further research is needed in order to determine to what level of detail this should be carried out in order to effectively support clients requirements throughout the lifecycle of the building. This way it should be possible to support maintenance tasks for the occupancy and post-occupancy stages from earlier phases of the building lifecycle, supporting a whole lifecycle approach for maintenance (BSRIA 2009).

EVALUATION OF IFC/COBIE SUPPORT FOR ASSET REGISTERS

In order to assess IFC and COBie support of facility managers' information requirements, an initial analysis was carried consisting of the evaluation of the support of asset register information requirements by IFC/COBie data entities. This analysis compares asset register requirements specified in section 9.7.4 of BS 8210 (BSI, 2012) with IFC/COBie entities from the buildingSMART IFC4 specifications (buildingSMART 2014b). The definition of COBie data drops adopted in study follows the definition proposed in the COBie Data Drops document (Cabinet Office 2012). The results from this analysis can be found in Table 1.

Table 1 - Evaluation of IFC/COBie support for asset register requirements defined in BS 8210 (BSI, 2012, buildingSMART 2014b)

Asset register information requirements (BSI, 2012)	IFC 4	COBie 2.4 (Spreadsheet xml)	COBie Data drop
a) identification number or unique reference for the asset;	SerialNumber (Pset_ManufacturerOccurrence)	component sheet - SerialNumber	4 – as-built
	BarCode (Pset_ManufacturerOccurrence)	component sheet - BarCode	4 – as-built
		component sheet - TagNumber	4 – as-built
		component sheet - AssetIdentifier	4 – as-built
b) make and/or model;	ModelReference (Pset_ManufacturerTypeInformation)	type sheet - ModelReference	4 – as-built
c) manufacturer;	Manufacturer (Pset_ManufacturerTypeInformation)	type sheet - Manufacturer	4 – as-built
d) vendor, if different to manufacturer;	Manufacturer (Pset_ManufacturerTypeInformation)	type sheet - Manufacturer	4 – as-built
e) date of manufacture;	ProductionYear (Pset_ManufacturerTypeInformation)		4 – as-built
f) date of acquisition, installation or completion of construction;	AcquisitionDate (Pset_ManufacturerOccurrence)	component sheet - InstallationDate	4 – as-built
	WarrantyStartDate (Pset_Warranty)	component sheet - WarrantyStartDate	4 – as-built
g) location of asset;	IfcSpace	Component sheet - Space	4 – as-built
h) whether or not access equipment is required;		Job sheet	5 – O&M

i) whether or not the asset is subject to a permit-to-work requirement		Job sheet	5 – O&M
j) initial cost;	IfcCostValue		4 – as-built
k) predicted lifetime;	ExpectedLife (Pset_ServiceLife)	type sheet - Expected Life	4 – as-built
l) specification;		type sheet - all	4 – as-built
m) replacement cycle;		Job sheet	5 – O&M
n) cost breakdown;			5 – O&M
o) servicing requirements, including type and frequency of service;		Job sheet	5 – O&M
p) other maintenance required;		Job sheet	5 – O&M
q) maintenance costs;	ReplacementCost	type sheet - ReplacementCost	5 – O&M
r) accumulated depreciation;			5 – O&M
s) written-down value;			5 – O&M
t) source of components and spare parts, where applicable			5 – O&M
u) energy consumption and, where applicable, energy-efficiency rating;	SustainabilityPerformanceDescription / Environmental (IfcTypeObjectProperty)	type sheet - SustainabilityPerformance	4 – as-built
v) identification of hazardous or other risks to people or property.	Pset_Risk		4 – as-built
Total number of unsupported attributes	**10/22**	**7/22**	

USE CASE DEVELOPMENT

In the context of this research, a use case has been developed in order to demonstrate IFC/COBie support of specific data used in lifecycle planning (i.e. Service Life), and how building owners can specify these data requirements. The development of this use case was based on the Information Delivery Manual (IDM) methodology and the definition of Employer's Information Requirements (EIR). The IDM methodology aims to document processes and support information exchanges between AEC industry stakeholders. Information Delivery Manuals can be used to support specific use cases in the AEC industry in the form of general guidance for the involved stakeholders, as well as for the development of software specifications (ISO 2010, Volk et al. 2014). IDMs can be bound to specific data types and software applications, or remain independent from these (ISO 2010). EIR specify the owner's requirements throughout the lifecycle of the building, and can be supported by COBie data (BSI 2014b).

The goal of the developed use case is to showcase the production of COBie data drops according to the owner's requirements. Specific owner requirements in this use case include the specification of Service Life data for mechanical components according to ISO 15686-4 (ISO, 2014). Use case development follows the IDM methodology for the definition of the overall process, relationships between actors, and exchange requirements which support the defined tasks. In this use case, specific tools, data models, and standards were used. EIR was used in the identification of standards supporting the data exchanges as well as IT tools used in the use case.

Figure 1 outlines the underlying process supporting the development of the use case, depicting the sequence of tasks and data support in the form of exchange requirements. Table 2 specifies the owner's information requirements. In the following sections, the development of tasks 5.1 to 5.4 will be detailed.

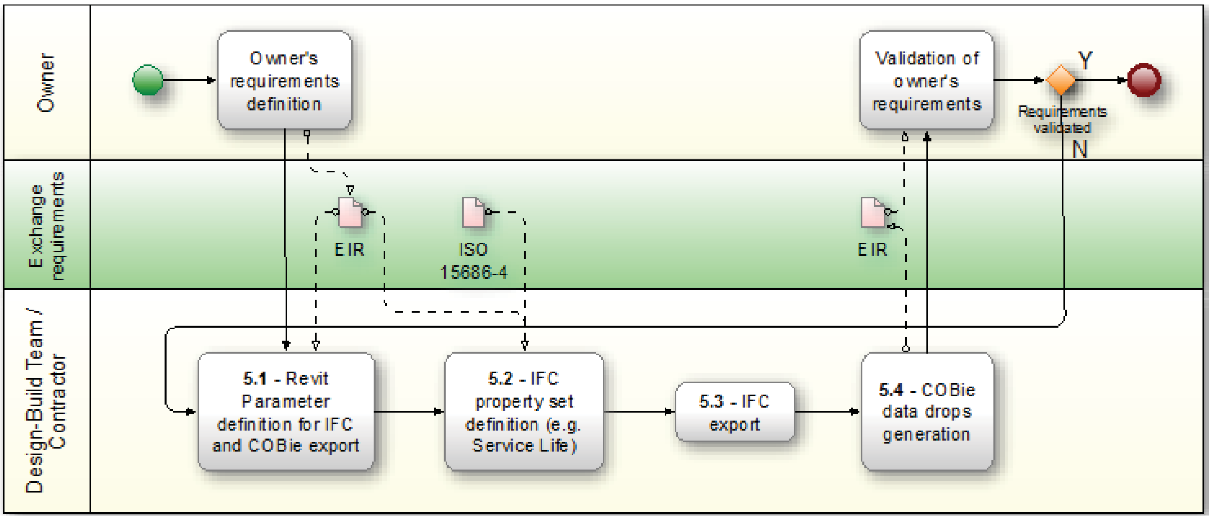

Figure 1 – Overall process supporting the development of the use case

Table 2 – Employer's Information Requirements (EIR) definition

Task	Software requirements	Supporting standards
5.1	Revit 2014	ISO 15686-4
5.2	Visual C# Express	**Exchange objects**
5.3	Open IFC Revit Exporter	Pset_ServiceLife (ISO 15686-4 Annex A)
5.4	COBie Toolkit	

Revit Parameter definition for IFC and COBie export

The development of this use case is based on an existing building model "Project 1. Duplex Apartment" (East 2014). Since COBie is a subset of IFC, COBie files will be generated from IFC files. Revit allows the mapping of specific objects to IFC entity types through definition in the IFC Export Classes dialog box (Autodesk 2014b). Since Revit object categories are defined more broadly than the corresponding IFC entities, when exporting from Revit to IFC using the default settings, some components will not be correctly mapped (USACE 2011). Two additional parameters have been added to the Revit project template as shared project parameters available to every object type to override an individual family's IFC export category (Autodesk 2014a):

- IfcExportAs: This parameter should be filled in with a valid IFC entity type.
- IfcExportType: This parameter should be filled in with the IFC Predefined Type setting.

The mapping of these parameters to IFC types and instances can be accomplished using the IFC 2x3 final release documentation (buildingSMART 2014c). These parameters had already been defined in the obtained building model for selected M&E components.

The Open IFC export for Revit plugin allows the definition of custom property sets in a text file which provides the correct mapping of COBie parameters from the IFC files generated in Revit. COBie parameters were defined as shared project parameters in Revit and their specification was defined based on the template file from the IFC for Revit project "IFC2x3 Extended FM Handover View.txt" (Autodesk 2014b). In order to automate the creation of shared parameters, the Revit API was used to define shared type parameters for the Type sheet and to automatically assign the category field from the NBS Uniclass 2 Keynote file for Revit (Hamil 2012).

IFC Property Set definition

To demonstrate the support of specific asset register requirements identified in Table 1, property set Pset_ServiceLife proposed by ISO 15686-4 (ISO, 2014) was added to the exporter as a common property set. This was achieved by editing the source code from the IFC for Revit project (Autodesk 2014b).

The source code consists of a C# Solution including 3 projects: Install, BIM.IFC.Common, and Revit.IFC.Export. In order to add property sets to the exporter, the ExporterInitializer.cs file from the Revit.IFC.Export project was edited to include the property set definitions. The Revit.IFC.Export was then compiled and the resulting Revit.IFC.Export.dll file was used to replace the default class library from the Open source IFC Exporter.

An excerpt from the method `InitPropertySetServiceLife` for the definition of properties from the Pset_ServiceLife proposed in ISO 15686-4 can be found below (not all properties are included):

```
private static void InitPropertySetServiceLife(IList<PropertySetDescription> commonPropertySets)
        {
            //property set description
            PropertySetDescription propertySetServiceLife = new PropertySetDescription();
            propertySetServiceLife.Name = "Pset_ServiceLife";
            //sub-type of ifcelement
            propertySetServiceLife.EntityTypes.Add(IFCEntityType.IfcElement);
            PropertySetEntry ifcPSE = PropertySetEntry.CreateText("ServiceLifeType");
            propertySetServiceLife.AddEntry(ifcPSE);
            ifcPSE = PropertySetEntry.CreateRatio("Utilization");
            propertySetServiceLife.AddEntry(ifcPSE);
```

Finally, Service Life parameters were defined as shared type parameters in Revit to enable export to IFC and COBie.

IFC Export

Following the definition of shared project parameters for IFC and COBie entities and to support the Service Life property set, it is possible to export the building model as an IFC file.

A specific export setup was defined in the open source IFC exporter for Revit to support the definition of custom property sets in a text file. Specific COBie parameters defined in the text file are accounted for by selecting the "Export user defined property sets" option. The Service Life Property set is accounted by selecting the default option "Export IFC common property sets". In order to support the use of Uniclass 2 classification in COBie, shared project parameters defined for classification fields were indicated in the IFC assignments panel of the open IFC exporter.

Solibri Model Viewer was used for the visualization of Uniclass 2 Classification attributes and Pset_ServiceLife attributes for a Boiler element in the model (Figure 2).

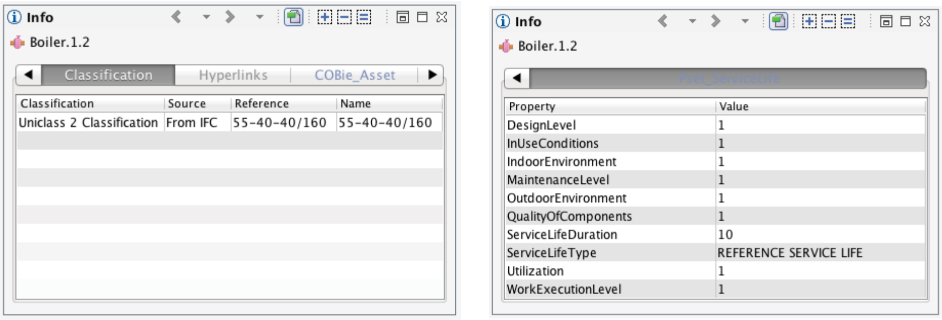

Figure 2 - Uniclass 2 Classification attributes and Pset_ServiceLife attributes for a Boiler element in the IFC model in Solibri Model Viewer

Generation of COBie Data Drops from IFC files

In order to generate COBie data drops from the IFC exports, the COBie Toolkit was used. COBie Toolkit allows for the export of certain IFC entities based on ObjectIDM plugins. These can be used to manage the contents of COBie drops, e.g. through the exclusion of information about products which are not tracked as assets by facility operators (ERDC 2013). In this experiment, the default COBieIDMPlugin was used. The IFC file is loaded into the COBie toolkit and it is converted to COBie internally (ERDC 2013). It is then possible to export the file in the preferred COBie format. In this experiment the file was exported as a COBie spreadsheet. Figure 3 shows the representation of several attributes in the Type sheet for Heat Exchanger and Boiler elements, including: Uniclass 2 Classification; Asset Type, Manufacturer, Model Number, Warranty parameters and reference to the element's IFC Type. Figure 4 shows the representation of the property set Pset_ServiceLife in the Attribute sheet.

1	Name	atedBy	CreatedOn	Category	Description	AssetType	Manufacturer	delNumber	WarrantyGuarantorParts	WarrantyDurationParts	rrantyGuarantorLabor	rrantyDurationLabor	WarrantyDurationUnit	ExtSystem	ExtObject
2	147 kW	Joaoı	2014-07-3(	55-40-40/160	147 kW	Fixed	Vokera	36HE	1	5	n/a	n/a	Year	Autodesk	IfcBoilerType
3	Radiator -	Joaoı	2014-07-3(	60-45-35/120	Radiator -	Fixed	Stelrad	K1	1	5	n/a	n/a	Year	Autodesk	IfcHeatExchangerType

Figure 3 - Uniclass 2 (2012) category in Type sheet - COBie spreadsheet

1	Name	atedBy	CreatedOn	Category	SheetName	RowName	Value	[illegible]	ExtSystem	ExtObject
44	DesignLevel	Joaoı	2014-07-3(	Requirement	Component	M_Hot Water Boiler - 59-440 kW:147 kW:530072	1.0	n/a	Autodesk	Pset_ServiceLife
45	OutdoorEnvironment	Joaoı	2014-07-3(	Requirement	Component	M_Hot Water Boiler - 59-440 kW:147 kW:530072	1.0	n/a	Autodesk	Pset_ServiceLife
46	QualityOfComponents	Joaoı	2014-07-3(	Requirement	Component	M_Hot Water Boiler - 59-440 kW:147 kW:530072	1.0	n/a	Autodesk	Pset_ServiceLife
47	IndoorEnvironment	Joaoı	2014-07-3(	Requirement	Component	M_Hot Water Boiler - 59-440 kW:147 kW:530072	1.0	n/a	Autodesk	Pset_ServiceLife
48	Utilization	Joaoı	2014-07-3(	Requirement	Component	M_Hot Water Boiler - 59-440 kW:147 kW:530072	1.0	n/a	Autodesk	Pset_ServiceLife
49	InUseConditions	Joaoı	2014-07-3(	Requirement	Component	M_Hot Water Boiler - 59-440 kW:147 kW:530072	1.0	n/a	Autodesk	Pset_ServiceLife
50	WorkExecutionLevel	Joaoı	2014-07-3(	Requirement	Component	M_Hot Water Boiler - 59-440 kW:147 kW:530072	1.0	n/a	Autodesk	Pset_ServiceLife
51	ServiceLifeType	Joaoı	2014-07-3(	Requirement	Component	M_Hot Water Boiler - 59-440 kW:147 kW:530072	REFERENCE SERVICE LIFE	n/a	Autodesk	Pset_ServiceLife
52	ServiceLifeDuration	Joaoı	2014-07-3(	Requirement	Component	M_Hot Water Boiler - 59-440 kW:147 kW:530072	10.0	n/a	Autodesk	Pset_ServiceLife
53	MaintenanceLevel	Joaoı	2014-07-3(	Requirement	Component	M_Hot Water Boiler - 59-440 kW:147 kW:530072	1.0	n/a	Autodesk	Pset_ServiceLife

Figure 4 - Pset_servicelife: Property definitions for a Revit Family in Attribute sheet – COBie spreadsheet

DISCUSSION

The objective of this use case was to assess the suitability of open BIM standards (IFC/COBie) and a building modelling tool (Revit) to capture and integrate asset register and service life information in order to support specific owners' requirements.

In this use case it was demonstrated how service life parameters defined in ISO 15686-4 can be represented in IFC and COBie. The representation of service life and service life factors are an important input for the assessment of life cycle costs in the use phase of buildings (ISO 2011). They can also be considered as inputs in the decision making process to support Design for maintainability as proposed in the Soft Landings methodology (BSRIA 2009).

IFC/COBie support for Asset Register data

In order to evaluate the support of asset register information requirements defined in BS 8210 (BSI, 2012) by IFC/COBie, an analysis was carried out comparing how these requirements can be captured in specific IFC/COBie entities and its results presented in table form (Table 1). It can be noted that several of these requirements are not directly supported in IFC (10 out of 22) and COBie (7 out of 22), especially for the use phase of buildings (data drop 5). Gaps that were identified in this analysis include capital information such as costs breakdown, written down value of assets, accumulated depreciation, and sources of components (Table 1). Several information requirements for maintenance tasks which are not directly supported in IFC can be represented in the Job sheet (COBie): requirements for access equipment, permit-to-work requirements, replacement cycle, servicing requirements and other maintenance requirements.

Gaps found in this analysis are consistent with previous results from the literature stating that the current IFC standard does not include all the required properties and relationships related to the O&M phase (Motamedi et al. 2014). However, it should be noted that in the case of IFC, and due to the flexibility of its schema, FM software providers might be able to support the missing information requirements in an indirect fashion. Also, the possibility to include additional information in IFC and COBie files using custom property sets, or through extensions to the model schemas, could contribute to increase the support of these information requirements.

Generation of COBie data drops for the in-use stage

The approach adopted to provide accurate IFC exports from Revit in order to support the creation of COBie files was based on the definition of specific type and instance IFC parameters for M&E components using IfcExportAs and IfcExportType shared project parameters and the specification of dedicated shared parameters for the mapping of COBie entities.

Using the proposed approach in select M&E components, it was possible to obtain well defined IFC models and COBie data drops (Figures 2, 3 and 4). It should be noted however that the application of this process for a real project can be time consuming, since the user has to find out which components are not correctly exported to IFC, and define the correct IFC types and entities for each of these components. Also, COBie shared parameters must be defined for each COBie entity and they must be edited for each component and/or type. In this regard, it was shown that the Revit API can automate this task, through the definition of shared type parameters for the COBie Type sheet and automated assigned of the category field based on the NBS Uniclass 2 Keynote file. In order to support specific requirements from the client and from facility managers, the definition of COBie parameters and the contents of the COBie Attribute tab – which includes IFC property sets - should be agreed on beforehand. The management of information in COBie data drops can also be supported by the use of ObjectIDM plug-ins in the COBie Toolkit, which specify what elements are included in the COBie drops.

IFC Property Set definition

In order to demonstrate the support of specific owner's requirements by IFC/COBie, property set Pset_ServiceLife was defined by editing the open IFC Revit exporter source code. This property set has been proposed by buildingSMART for IFC4 (buildingSMART 2014b) and by ISO 15686-4 (ISO, 2014), but is currently not supported in the open source IFC Revit exporter. The definition of this property set demonstrates how it is possible to customize the open source IFC Revit exporter by adding custom property sets to IFC. The process followed in this use case shows how custom property sets can be defined and represented in IFC and in the COBie attribute sheet in order to support specific maintenance tasks (e.g. Service Life Planning).

However, some limitations were found in this process: Upon checking the official IFC4 documentation (buildingSMART 2014b) against the list of supported IFC Entity Types by the open source exporter (defined in IFCEntityType.cs file), it was found that not all IFC Entity Types are supported. For example, the IFC exporter does not support the definition of IfcPropertyBoundedValue, which defines a property object which has a maximum of two (numeric or descriptive) values assigned, the first value specifying the upper bound and the second value specifying the lower bound (IFC documentation). For this reason, while the official IFC documentation recommends the use of IfcPropertyBoundedValue entity type for the Service Life property, the definition from ISO 15686-4 Annex A using type Real was used instead. While this shows current limitations in the open source IFC exporter for Revit, in the future this functionality can be added to the code.

CONCLUSIONS

This study focused on the development of a use case based on the IDM and EIR methodologies, with the objective of assessing the suitability of open BIM standards (IFC/COBie) and building modelling tools for the capture and integration of FM information.

Results from this use case have shown that while IFC/COBie do not support all information requirements for asset management by default, they allow the user to add some of the required information, particularly in the form of property sets. It can be concluded that IFC and COBie can be used for the definition of asset registers and to support owners' requirements. In this use case, limitations in the IFC/COBie standards and used tools have been highlighted and improvements have been proposed.

The obtained results constitute an important input for future developments in this research, including the evaluation of IFC/COBie capabilities to provide decision support to owners and facility managers based on the optimization of lifecycle costs in the maintenance phase. Having outlined the process and information requirements supporting the use case, the proposed approach can be improved through the automated checking of owners' requirements against the COBie deliverables, following the BS 1192-4 code of practice (ISO 2014b). This process should increase the support of owner's requirements throughout the lifecycle of the building, and specifically improve the transition between the construction and use phases, in line with the Soft Landings framework. It is also expected that the results from this study can be used to improve current BIM standards and software applications to support the various stakeholders in the AEC industry. Finally, these results constitute an important contribution for the main objective of this research, which is to enable decision support to building owners and facility managers during the use phase of buildings.

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THE EFFICACY OF VIRTUAL REALITY TECHNOLOGIES RELATIVE TO TRADITIONAL METHODS OF ASSESSING PROJECT STATUS: AN EXPERIMENTAL STUDY[1]

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ABSTRACT: *Effective construction progress monitoring is crucial for project coordination. Traditional methods consist of manual as-built data collection from construction sites, drawings, schedules, and daily reports. Due to extensive workload, these methods are time-consuming and labor intensive. To address these limitations, research on virtual reality technologies that apply image-based visualization techniques for recognition of project as-built status and visualization of construction progress is increased in recent years. However, there is an opportunity for evaluating and validating the success of these technologies for monitoring construction projects. This paper tests and evaluates a virtual reality technology called VR Doc for visualization and detection of a construction project progress, and addresses its potential in monitoring and documenting project as-built status over time. The validation is geared towards identifying the advantages of newly developed virtual reality technologies over traditional methods of monitoring project progress, as well as their constraints for implementation in the construction environments. Hereto, we first review and discuss our previous research about virtual and augmented reality technologies. Then we present the validation results based on the pilot study conducted among four groups of undergraduate civil engineering students. Finally we summarise and recommend technologies and alternative applications that can increase virtual reality technologies usability.*

Keyword: *Virtual reality, Augmented reality, Pilot study, Comparison, Construction, Project status*

❖ INTRODUCTION

Current manual methods for project progress monitoring are not optimum and have limitations in monitoring project progress precisely, objectively, and in a timely manner. These methods are imprecise as “there is a strong tendency to let project inputs serve as surrogate measures of outputs” (Meredith and Mantel 2014, p. 246). Poor quality and subjective manually collected data along with visually complex progress reports do not effectively represent multivariable progress information such as scope, schedule, cost, and performance (Golparvar-Fard et al. 2009). To address these limitations, project participants increasingly rely on image-based virtual and augmented reality technologies in recent years. However, rapid and widespread use and implementation of virtual reality technologies in the construction industry often fails since their benefits and limitations remain somewhat unclear. Therefore, there is a need for more research on the efficacy of current virtual reality technologies relative to traditional methods to identify their values and benefits.

This study is built on the authors’ previous research about virtual and augmented reality technologies to compare project as-built statuses and thereby monitor project progress over time. The goal of this research is to investigate the efficacy of these technologies relative to traditional methods of assessing project status by conducting an experimental study. We first summarise our previous literature reviews of virtual monitoring technologies for construction management. Then we present the investigation results based on a pilot study conducted with four groups of civil engineering students to identify the advantages and disadvantages of a virtual reality technology. Finally in the conclusion section, we assess the experimental method for evaluating virtual technologies, and recommend to researchers and practitioners how to improve virtual reality technologies for monitoring project progress.

BACKGROUND

Virtual reality (VR) is an interactive computer generated environment with three-dimensional objects and locations that can simulate both planned/designed models and real world scenes. Augmented reality (AR) gives a

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view of the real world where elements are superimposed by computer generated files such as graphics, sounds, videos, or digital information.

This paper builds on the authors' previous publications about the application of image-based virtual and augmented reality technologies in the construction industry. In this section we summarize our previous in-depth literature reviews and analysis, and discuss how these literature reviews influenced the efficacy assessment that is described in this paper. Virtual and augmented reality dimensions (i.e., the headings shown in the first column of Table 1) and categories (i.e., items shown in the subsequent columns of Table 1), have been defined in our previous literature reviews. For example, the project phase dimension includes the categories: procurement, construction, and commissioning.

Our Previous Research

Rankohi and Waugh conducted an in-depth literature review of virtual reality technologies within 259 journal articles found through a key word search for "virtual reality" in construction engineering related journals. Virtual technologies greatly benefit construction projects by enhancing site safety, enabling construction professionals to test alternative construction methods, allowing more accurate sequencing of operations, and presenting a novel way of collaboration and communication between designers, suppliers and contractors. The literature has increasingly focused on prominent virtual technology roles such as visualization and simulation in the construction and design phases of the AEC projects; in parallel, the literature addresses issues faced by audiences such as the design group and project managers in building/commercial projects. However, the literature shows that industry participants prefer to pilot VR technologies on a few selected projects rather than adopting or piloting the technology across their organization. (Rankohi and Waugh, 2013a)

Rankohi and Waugh also conducted an in-depth literature review augmented reality technologies 133 articles found through a key word search for "augmented reality". Project participants can benefit from various applications of augmented reality technologies such as virtual site visits, comparing as-built and as-planned status of projects, pre-empting schedule disputes, enhancing collaboration opportunities, and planning/training for similar projects. The AR literature has increasingly focused on the demonstration of visualization and simulation applications for comparison of as-planned versus as-built statuses of the project during the construction phase to monitor project progress and address issues faced by field workers. However, augmented reality literature shows a gap in applications that access these technologies over internet; the future trend is toward using web-based mobile augmented systems for field construction monitoring. (Rankohi and Waugh, 2013b)

Rankohi and Waugh analysed the use of VR and AR technologies to compare different statuses of construction projects 37 articles found within four well-known journals in the AEC industry. Comparing projects status over time is one of the most popular applications of virtual and augmented reality technologies. The literature shows that project status comparison is conducted in different modes (model versus model, model versus reality, and reality versus reality), and through different techniques (manual versus automated, split screen versus overlay). The literature typically assumes that project managers compare project models (drawings, 3D/4D models) with realities (as-built photographs, videos) using automated overlay techniques for monitoring progress during the construction phase of a project. However, the literature shows a lack of research in other modes of comparison such as comparing model versus model and reality versus reality with split screen techniques and also in other phases of projects such as commissioning, maintenance, and reconstruction/renovation phases. (Rankohi and Waugh, 2013c)

Rankohi and Waugh reviewed image-based virtual construction as-built monitoring technologies within 93 articles published in 16 civil engineering journals and conferences. The literature shows that during the last few years significant research has been undertaken on photographic modeling techniques for monitoring construction projects. Daily construction photographs are not only used for documentary purposes, but also can be used for comparing project as-built status over time in all phases of a construction project. The literature shows that researchers mainly seek to develop an automatic image-based monitoring system to connect the building information models and the project schedule to daily construction images. However, only a few studies show that the success of the developed systems has been tested and validated in practice. Hence, there is an opportunity to evaluate and validate the success of image-based modeling approach for monitoring construction projects. (Rankohi and Waugh, 2014)

The literature shows new virtual and augmented reality technologies are evolving rapidly and there is very little quantitative information on their benefits and barriers, therefore an opportunity exists for more research and development in the application of these technologies in the construction industry. In particular their comparison application, comparison modes and comparison techniques in different phases of a construction project should be further investigated. To achieve this goal, the success of current image-based modeling virtual technologies should be tested and evaluated. Table 1 shows the most and the least prominent virtual and augmented reality dimensions and categories in the literature and identifies the categories that are selected for this study. The selected categories in this study are shown in bold in Table 1. As shown, to fully address the research goal, we selected some of the least (i.e., **reality vs. reality**, **web-based**) and some of the most (i.e., **project manager**, **construction**) prominent categories in VR and AR literature.

Table 8: Most and least prominent topics in literature versus the selected categories in this study

	R&W-2013a	R&W-2013b	R&W-2013c	R&W-2014
Target audience				
Least	End user & Student	End user	End user	
Most	Design team/**project manager**	Workers	**Project manager**	
Technology role				
Least	Information modeling	Education/training & Inspection/safety	Updating the model	Productivity analysis
Most	**Visualization/simulation**	**Visualization/simulation** & Communication/collaboration	**Progress Monitoring**	**Progress Monitoring**
Project phase				
Least	Commissioning	Procurement	Procurement & Commissioning	Commissioning
Most	**Construction**	**Construction**	**Construction**	**Construction**
Comparison mode				
Least		Model vs. model/**reality vs. reality**	Model vs. model/**reality vs. reality**	
Most		Model vs. reality	Model vs. reality	
Comparison techniques				
Least			Manual **/split screen**	Manual
Most			Automated overlay	Automated overlay
Industry sector				
Least	Residential	Residential		
Most	**Building/commercial**	**Building/commercial**		
Technology type				
Least	Immersive	Immersive		
Most	**Non-immersive**	**Non-immersive**		
Delivery type				
Least	**Web-based**	**Web-based**		
Most	Standalone	Standalone		
Organization type				
Least	Owner	Owner		
Most	**Contractor**	**Contractor**		
Improvement focus				
Least	Organization	Organization		
Most	**Project**	**Project**		

Virtual Monitoring Systems

Golparvar-Fard defines project monitoring as "collecting, analyzing, recording, and reporting information concerning key aspects of project performance at the appropriate level of detail required by project managers and decision makers." However, monitoring construction projects in terms of project progress and work performance is considered the most challenging problem. Virtual information technologies can play a vital role in reducing such problems by visualizing project as-built status, distributing project information, and automating progress measurements which enable project decision makers to make timely decisions. (Golparvar-Fard, 2009)

Limited Field of View

Although the limited field of view of panoramic images was not a problem in our pilot study, it is worth mentioning that in indoor scenes this problem can cause identifying less than the maximum changes, which indicates the importance of ensuring that a set virtual reality panoramas captures all necessary locations and information for progress tracking. For example issues such as covering all parts of the ceiling to find mechanical (HVAC, plumbing) changes, or all part of the interior space to find the expected changes of doors/windows, or woods/plastics divisions need to be addressed. Moreover, extracting 3D spatial information from virtual reality panoramas will enable users to find more changes and increase the end results accuracy. To overcome such problems, researchers have conducted various research on panorama-based virtual reality technologies for monitoring construction projects. Dang et al. (2011) proposed a panorama-based semi-interactive 3D reconstruction framework for indoor scenes. Their framework overcomes the problems of limited field of view in indoor scenes and has the desired properties: robustness, efficiency, and accuracy. Shum et al. (1998), Li et al. (2004), Haeusler et al. (2008) also conducted research on 3D reconstruction from panoramas.

A PILOT STUDY TO EVALUATE VIRTUAL REALITY TECHNOLOGIES

We conducted a pilot study to evaluate virtual reality technologies and their applications in the construction industry. We selected Virtual Reality Documentation (VR Doc) software (www.vrdoc.ca), which was developed by the construction engineering and management group at the University of New Brunswick. VR Doc is a web-based panoramic project monitoring system that provides a means to document and display the progress of construction projects through virtual reality panoramas. While VR Doc has many applications, performing virtual site visits to monitor project as-built status has been a primary function.

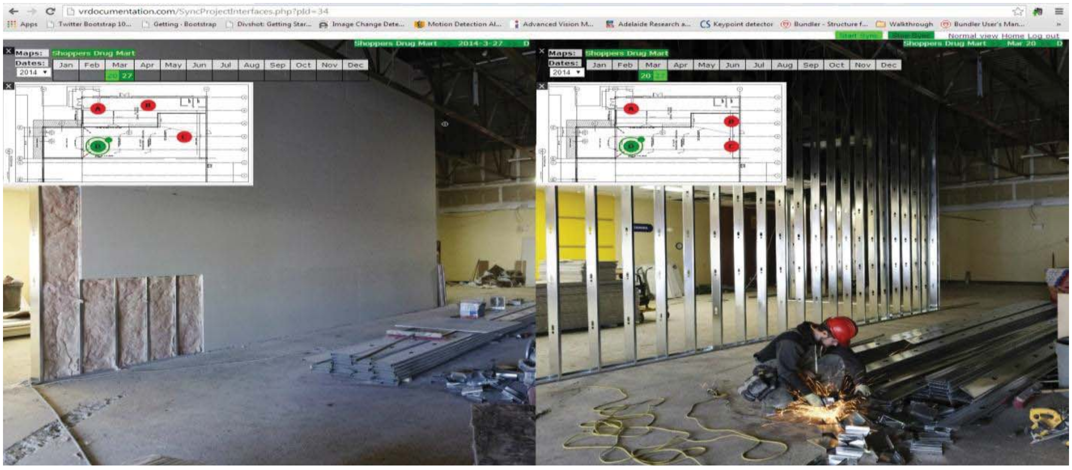

Figure 1: VR Doc application for monitoring project as-built status

Research Problem and Hypotheses

This study is a component of a graduate thesis conducted by the first author. The question that arises in this study is how, and to what extent, virtual reality technologies would minimize the effort to monitor, and improve the accuracy of monitoring project progress? The primary hypothesis of this research is that the use of virtual reality technologies will reduce the time required to find discrepancies between actual and expected construction performance by 25%. A secondary hypothesis is that those research participants using virtual reality technologies will find a larger number of changes (discrepancies) than those participants not using virtual reality software.

Data Collection

We selected a small commercial building renovation project located in Fredericton, NB to perform this pilot study. Based on the previously performed literature review and a preliminary site visit, a research questionnaire was developed and distributed among the research participants. We used the Canadian Master Format (www.spex.ca) categories to develop questionnaire items based on the hypotheses and the selected project's specifications. A compressed version of a completed questionnaire is shown in Table 2.

Table 2: Research questionnaire

	First visit **on-site** ☐ **in-office** ■ **Start time:** **End time:**	**Second visit** **on-site** ☐ **in-office** ■ **Start time:** **End time:**
	Notes on Status	**Notes on Changes in Status**
Concrete	*No work*	*No change*
Masonry	*No work*	*No change*
Metals	*Some steel studs installed*	*Steel studs installation is completed*
Wood & plastics	*No work*	*No change*
Insulation & vapor barrier	*No work*	*Insulation installed in interior partition*
Doors & windows	*No work*	*Steel studs cut for doors' frame, window work started, demolition is started*
Finishes (ceiling, walls, floor)	*No work*	*Gyprock on partition completed, & they crack filled, no change on floor & ceiling*
Mechanical (plumbing, HVAC, sprinkler)	*No work*	*No significant change*
Electrical	*No work*	*No significant change*
Stored materials	*Steel studs, plywood, drywall, insulation*	*Most stored material are gone*
Major equipment	*Two scissor lifts, two step ladders, vacuum*	*No change*

As shown, the questionnaire has two columns for notes. In the column entitled "First Visit," students were asked to write their notes on project status at the time of their first visit, while in the column entitled "Second Visit," students were asked to write their notes on changes in the project status at the time of their second visit. We primarily rated each student's notes based on the changes identified in the "Second Visit" column. This indicated to us how well they detected project progress with or without using virtual reality technologies. The italic text in Table 2 is the authors' assessment of status and changes in status. The authors filled out the questionnaire and assessed the project changes by using VR Doc in-office.

Comparison Groups

Empirical data for this study were collected in the form of a multi scale questionnaire. Twenty-eight undergraduate civil engineering students in a final year course at the University of New Brunswick participated in this research. The students were divided into four groups, referred to as the site-visual/site-visual group, the site-visual/office-pano group, the office-pano/office-pano group, and the office-split screen/office-split screen group.

As shown in Table 3, each group conducted an actual and/or virtual assessment of the selected project for two dates. The site-visual/site-visual group visited the project twice and filled out the questionnaire while on-site during both assessments. The site-visual/office-pano group visited the construction site for the first date, while for the second they used panoramic photographs captured on-site to virtually assess the status of the project while in-office. The office-pano/office-pano group and the office-split screen/office-split screen group did not physically visit the site. The office-pano/office-pano group used 360 degree panoramic virtual reality photographs twice (once for each of the two different dates), while the office-split screen/office-split screen group used VR Doc split screen interface (shown in Figure 1) which displays two panoramas in two frames of a window beside each other to virtually compare the project status on the two dates while in office.

Table 3: Group allocations by assessment date, location, method, and note

Group	**Site-visual Site-visual**		**Site-visual Office-pano**		**Office-pano Office-pano**		**Office-split screen Office-split screen**	
# of members	6		7		7		8	
Assessment	First Assessmt	Second Assessmt	First Assessmt	Second Assessmt	First Assessmt	Second Assessmt	First Assessmt	Second Assessmt
Status date								
= Mar. 20	✓		✓		✓		✓	
= Mar. 27		✓		✓		✓		✓
Location								
= on-site	✓	✓	✓					
= in-office				✓	✓	✓	✓	✓
Method								
= visual	✓	✓	✓					
= panorama				✓	✓	✓		
= split screen							✓	✓
Notes								
= status	✓		✓		✓		✓	
= changes		✓		✓		✓		✓

Results and Analysis

The following sections present the results of the survey. The results are presented in the order that the research hypotheses were introduced in section 3.1. Based on the hypotheses, we investigated three questions: (a) how long does it take for each group to detect the changes? (b) what is the accuracy of the detected changes for each group? and (c) what is the accuracy of the number of workers detected by research participants?

Primary hypothesis: time

Figure 2 shows the results of our time analysis for each group. As shown the site-visual/site-visual group spent more time than the other groups, and the office-split screen/office-split screen group spent less time than other groups to assess the project and find changes in the project status. Moreover, the second assessment took less time than the first, except for the site-visual/office-pano group who took more or less the same amount of time for each assessment.

Secondary hypothesis: changes

Our rating scale, which emulates a Likert scale, is shown in Table 4. A full list of the average group member ratings by group and division is shown in Table 5. Investigation shows that students found less than the expected changes in all categories except: concrete, insulation, electrical, and major equipment.

Figure 3 shows the average detected changes (based on our rating scale) by group. As shown the site-visual/site-visual group has the highest rating and the site-visual/office-pano group has the lowest rating of detected changes among the groups. Preliminary analysis of standard deviation indicates that there is no significant variation among the ratings of detected changes for different groups and divisions.

Figure 2: Time analysis results

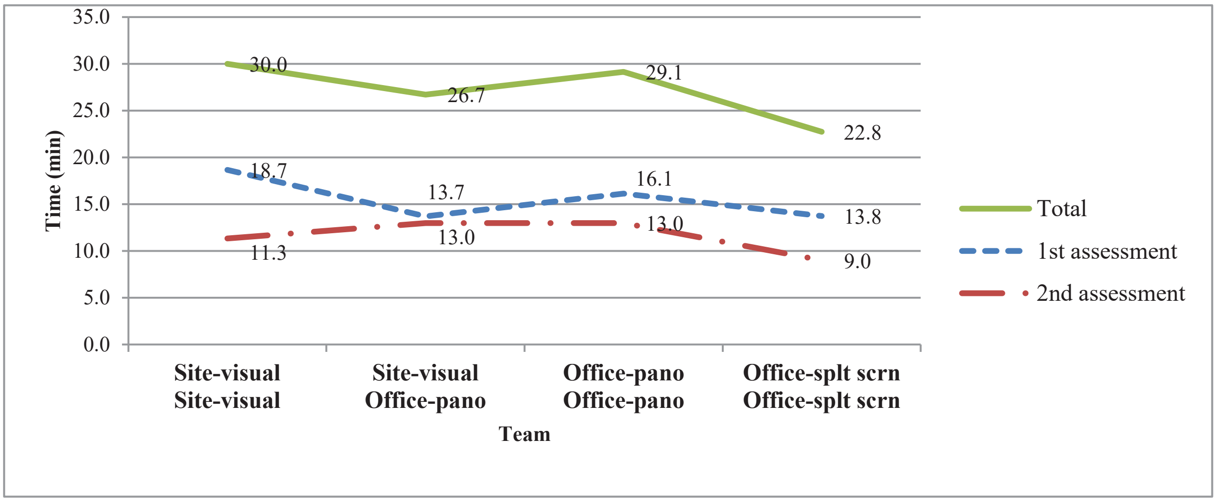

Table 4: Rating scale for change detection

Rating	Description
1	Identified a lot less than the expected changes
2	Identified less than the expected changes
3	Identified the expected changes
4	Identified more than the expected changes
5	Identified a lot more than the expected changes

Table 5: Rating of detected changes by group and division

	Concrete	Masonry	Metals	Wood/ plastics	Insulation	Doors/ Windows	Finishes	Mechanical	Electrical	Stored materials	Major equipment
Site-visual Site-visual	3.2	3.2	3.5	2.3	3.0	2.5	3.2	3.5	2.7	3.7	3.5
Site-visual Office-pano	3.0	3.0	2.3	2.6	2.7	2.1	3.0	2.9	2.6	2.6	2.6
Office-pano Office-pano	3.0	2.9	2.1	2.4	3.0	2.3	2.9	2.1	3.1	2.7	3.0
Office-splt scrn Office-splt scrn	3.1	2.9	3.1	2.5	2.9	2.1	2.6	2.5	2.9	2.9	2.9
Average	**3.1**	**2.9**	**2.6**	**2.5**	**3.0**	**2.2**	**2.8**	**2.3**	**3.0**	**2.8**	**3.0**

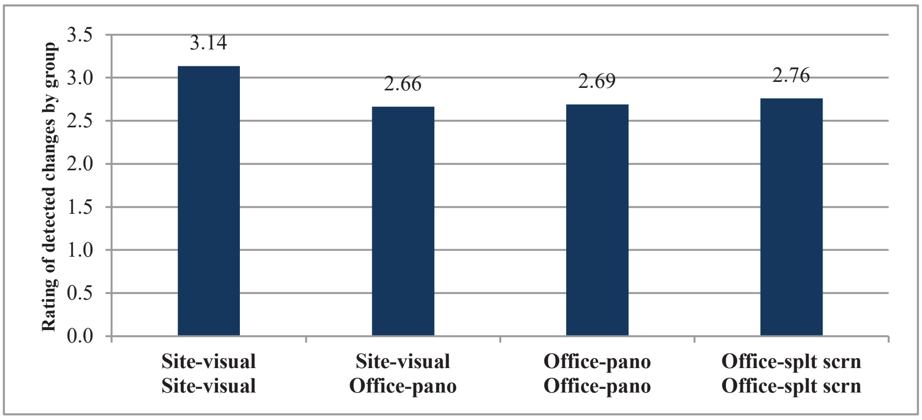

Figure 3: Average detected changes by group

The total percentage of correct answers for detected workers is shown in Figure 4. As shown, the site-visual/site-visual group found the correct number of workers for both of their assessments, while the office-split/office-split group found the least correct number of workers for both of their assessments.

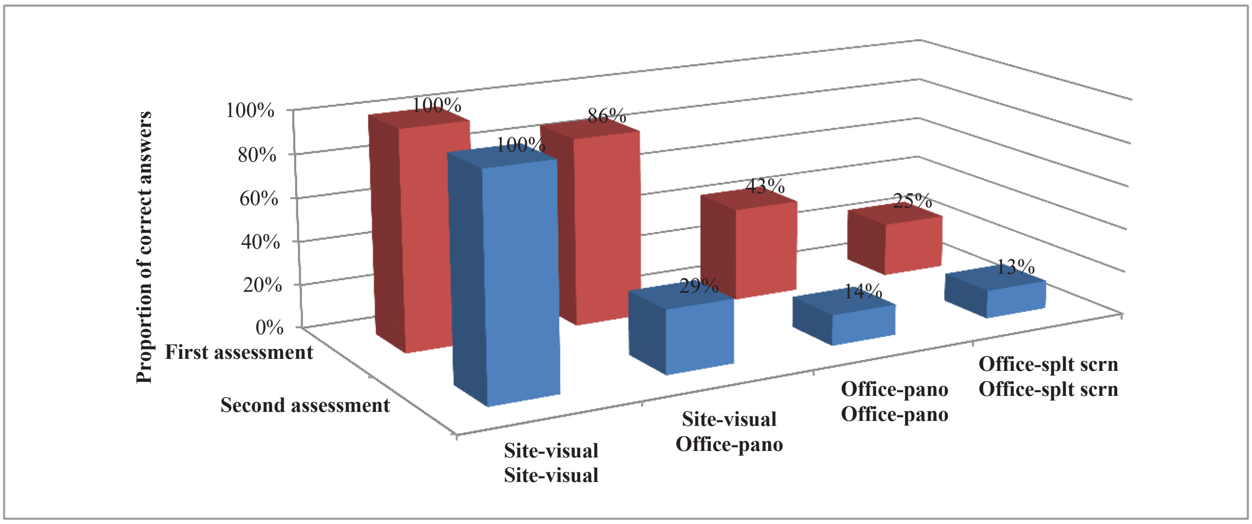

Figure 4: Percentage of correct answers for the number of workers by group

DISCUSSION OF RESULTS

The results analysis shows that those students who physically visited the site on different dates to assess project progress received the highest rating for the detected changes, and were the most likely to identify the correct number of total workers, but they spent more time (30 minutes) than other groups. While, those students who did not visit the site but instead used a split screen interface to assess project progress found the second highest number of changes and spent less time (22.8 minutes) than other groups to find those changes. However, they record the least correct answers in terms of total number of workers. There is a general trend that those groups who used more technology-enhanced methods, spent less time assessing the project.

Figure 2 shows that in the first assessment there is not a constant trend down, and the site-visual/office-pano group spent less time than other groups. We speculate that this may be an anomaly since this group was in rush due to the amount of work in progress while they were on-site. Figure 2 also shows that for the second assessment the site-visual/site-visual group spent significantly less time than for their first assessment. We speculate that once project participants got oriented to the site they were able to detect changes quicker than during their first assessment.

Figure 3 and Table 5 show that students who physically visited the project twice (the site-visual/site-visual group) found significantly more changes than other groups, and the students who only used a split screen interface (the office-split screen/office-split screen group) found slightly more changes than the site-visual/office-pano and the office-pano/office-pano groups. We speculate that the site-visual/site-visual group found more changes because they physically assess the site twice and the changes in the project status were more tangible and accessible for them than other groups. Moreover, we speculate that split screen allows user to see and compare panoramas next to each other without a need to rely on their memory to find changes on status.

Figure 4 shows that those groups who used virtual reality software have the least proportion of correct answers regarding to the detection of total number of workers. Since photographs can only capture specific instances in time, virtual reality panoramas are not useful tools for detecting moving objects such as workers, equipment, or operating machines.

The research results show that the first research hypothesis is confirmed which indicates that the split screen display reduces the time required to find discrepancies between actual and expected construction performance by 24% (~25%). However our second research hypothesis which indicates that students using virtual reality technologies will find a larger number of changes than those students not using virtual reality software is not confirmed within the scope this pilot study.

SUMMARY AND RECOMMENDATIONS

Summary

As discussed, the previous literature shows a lack of research in the application of virtual reality technologies to compare project realities (as-built status) with split screen techniques in design, maintenance, and reconstruction/renovation phases of a project. Moreover, only a few studies show that virtual reality systems have been tested and validated in practice. Therefore, there is an opportunity for evaluating and validating the success of these technologies for monitoring construction projects.

To fulfill these opportunities, we designed an experimental study to monitor project progress by using a virtual reality technology. We selected a small building renovation project and used VR Doc as an image-based virtual information technology to compare the project status over time. We conducted this pilot study using four groups of undergraduate civil engineering students at the University of New Brunswick to evaluate the application of virtual technologies for monitoring project progress.

Based on the results of this pilot study, we speculate that virtual reality technologies can significantly reduce the time and effort that project participants require for monitoring project statuses and detecting project changes. This test is done based on not counting the travel time, while in reality the result would be much higher without this assumption. In terms of the accuracy, traditional methods still cannot yet be fully replaced by these newly developed virtual technologies. The results show that project participants who used virtual reality technologies did not detect the correct number of on-site workers as opposed to the participants who physically visited the construction site.

This pilot study also shows that the current experimental methods for evaluating virtual reality technologies should be further assessed and improved in terms of research participants, research projects, research objectives, and research techniques.

Recommendations to Improve Technology

We speculate that due to the dynamic nature of construction environments and significant number of moving resources, image-based technologies which only provide visual data for construction participants might not be suitable tools for resource tracking or resource management. However by increasing the frequency of taking pictures and/or taking videos this problem can be solved.

We recommend that researchers improve virtual reality monitoring system's performance through applying techniques which enable users to extract visual information combined with spatial information. There are alternative spatial data extracting technologies on the horizon. Combining enhanced spatial data extracting techniques with developing virtual reality technologies will aid project managers to apply more quantitative analysis on construction sites. In summary, further research is recommended on the integration of actual as-built aerial or terrestrial panoramic images, as-built building information models (BIMs), RFID tracking technologies, 3D range point clouds produced by laser scanners, and virtual reality split-screen displays to record and monitor site activities.

Recommendations to Improve Experimental Method

We recommend that researchers conduct experimental studies on virtual reality technologies among a larger group of participants including participants from owners and contractors. Moreover, we recommend testing and evaluating these technologies in different phases of a construction project (such as initiation, design, and procurement phases) and in different types of projects (such as industrial, heavy/highway, and residential). Finally, we recommend that researchers evaluate different methods of comparing project status using virtual technologies such as semi-automatic and automatic methods.

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THE CHALLENGES OF ADOPTING BUILDING INFORMATION MODELLING (BIM) PRINCIPLES WITHIN SMALL TO MEDIUM SIZED ENTERPRISES (SMEs)[1]

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ABSTRACT: *Building Information Modelling (BIM) has recently attained widespread attention within the Architectural, Engineering and Construction (AEC) industry involving the Government, institutions and the private sector. The new 'evolution' of BIM represents the development of the "virtual buildings" concept through the use of computer-generated n-dimensional (n-D) models, to help architects, engineers, constructors, clients and Facility managers to simulate, plan, design, construct and operate the facility throughout its whole life cycle. This evolution is aimed to provide an increase in construction productivity while also resulting in improved profit margins and sustainability, with the growing focus on a low carbon future. However, It is not known if there is a true understanding of BIM or a clear plan to help the implementation of BIM within UK's industry specially for the small and medium enterprises (SMEs). In this paper, the possible use of BIM and future challenges for SMEs are discussed. First presented is the key concept of what BIM actually is including its advantages and disadvantages, highlighting the challenges to implementing BIM and why it is important for SMEs to understand these challenges especially within the current timeline of the UK BIM strategy. This research is based on the results of two recent questionnaire surveys along with case studies to present a quantitatively illustration of the potential benefits to SMEs implementing BIM.*

KEYWORDS: *Building Information Modelling (BIM), Small and Medium Enterprises (SME), BIM Implementation, BIM for SMEs, BIM Execution plan, BIM SME challenges.*

❖ INTRODUCTION

Since the UK government made a proposal in 2011 to implement BIM and required for all public projects to be formed using BIM level 2 by 2016, there have been a great growth of interest in BIM. However, this growth is mainly dominated by the large enterprises while most of the Small and Medium enterprises are left almost abandoned in this sensational evolution.

The intention of this paper is to investigate whether SMEs require support to reach the implementation requirement of BIM level 2, and to identify and present evidence of what challenges SMEs face when adopting BIM in their organisations. Since the UK Government is aiming to be number one BIM user in Europe over the next few years, a considerable amount of focus is therefore required to be given to the SMEs who dominate UK's construction industry and highly involved in a great percentage of UK public projects. However, no research has been carried out to outline the current position of SMEs in the UK and summarise their requirements to be part of this evolution. Therefore, practical research is essentially required to asses the current position of SMEs and the challenges that they are facing while trying to implement BIM in order to provide solutions to BIM implementation from the SMEs prospective.

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[1] Citation: Bataw, A., Burrows, M. & Kirkham, R. (2014). The challenges of adopting building information modelling (BIM) principles within small to medium sized enterprises (SMEs). In: N. Dawood and S.Alkass (Eds.), Proceedings of the 14th International Conference on Construction Applications of Virtual Reality, 16-18 November 2014, Sharjah, UAE.

Why BIM

As gathered from the UK governmental reports such as the National Audit Office NAO reports illustrates that the industry is currently suffering from many common problems from using the traditional fragmented way of working due to projects complexity, health and safety control, lack of communication and difficulty of time, cost and quality control (J.W. Hinze, J. and Teizer 2011). However, the implementation of BIM could help reducing these inefficiencies within the industry (Henrik C. J. Linderoth 2010).

The Journal of Building Information Modeling (JBIM) have published in 2009, 2010 and 2011 a series of pilot studies and case studies on projects using BIM in the US, demonstrating how BIM operates as a bridge to communicate regular and reliable information across the scope of the project offering a successful and a clear understanding between the architects, engineers, construction professionals, facility managers and building owners; enabling these professional members to stay synchronized to improve accuracy and make knowledgeable decisions in advance, which reduces waste and helps to ensure the project's success with a better control of cost, time and quality.

BIM is also considered to be a positive transition for designers, where they are supported by new means of technological tools that makes their work easier, smoother and faster while enhancing the quality of designs. Similarly, contractors can visually create models for estimating, fabricating and construction sequence within a shared collaborative model.

The design team and construction team feed information into the BIM platform. Once all required data information are placed within the BIM model, it can automatically present itself in floor plans, elevations, specifications, work sequences, quantity takeoff, etc. where all users can be able to access it and operate on it, instead of working from detached drawings and schedules in the form of countless separate paper documents. Information within BIM can also automatically adapt when changes occurs to a set of data, along with a clash detection tool if changes are unsuitable. This is different to the traditional fragmented practice of numerous individual sets of drawings, where design and construction teams have to go back and manually change each set of drawings, elevation, specification, work sequence and quantity takeoff etc. According to case studies by Kaner et al. (2008) and Eastman et al. (2011), the use of BIM on projects reduced the number of information requests and order changes; it also improved the productivity and efficiency, especially in the design stages.

Issues of BIM

As mentioned above, JBIM series has demonstrated how BIM can be of extreme benefit to the industry and could assist in improving the industry; however, the authors don't completely agree, as the use of BIM could also raise a vast number of issues that deserve serious consideration. Many clients in the UK are still hesitant toward the implementation of BIM as they are still uncertain and puzzled on what BIM really is. This is due to the nature of all participants within the industry and the high costs of BIM implementation owing to the required extensive training of all involved professionals, the cost of technical expertise, the costs of organising protocols and managing a network server to store and access the model.

Other issues stopping the Implementation of BIM are the Legal barriers surrounding liability, uncertainties to the Intellectual Property Rights, digital information exchange and ownership of the program, which could all be resolved in time.

BIM IMPLEMENTATION BARRIERS

As most of the above mentioned issues only occur during the implementation of BIM. The UK Government has adopted the BIM maturity Diagram approach developed by Mervyn Richard and Mark Bew in 2008 (BIM Industry Working Group, 2011) shown in (Figure 1). This approach has helped breaking down the implementation strategy of BIM in the UK into different levels. BIM level 1 is the use of design software features only within the design stage; this level is currently being used and widespread within the industry without any major implementation issues. On the other hand, BIM level 2 is an advanced method in using software technologies within separate disciplines. However, few things need to be considered and improved before the implementation of BIM Level 2 could take place within projects in the UK, as follow:

- The great need of intense awareness campaigns and training courses throughout the industry to clear the doubts and debates surrounding BIM.
- Likewise, full training is required for all professionals to get them equipped with their new responsibilities and roles throughout the use of BIM level 2.

- Contractual amendments and software measures to be arranged to protect from data corruption and software tool failures especially when different stakeholders using different tools.

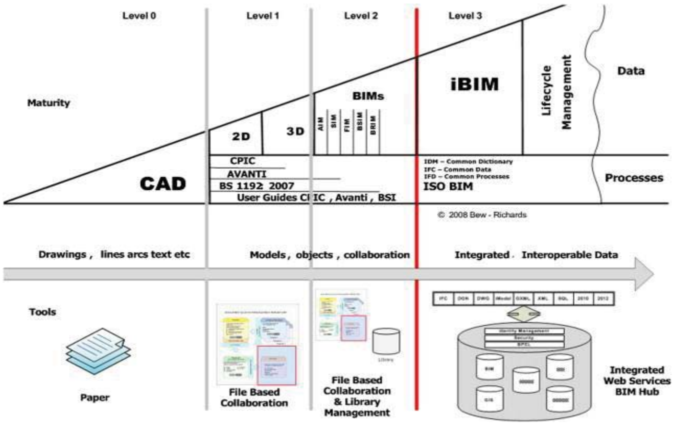

Figure 1: BIM Maturity Diagram (BIM Industry Working Group, 2011)

BIM Level 3 is the complete implementation of all BIM tools in a network-based integrated system. In this, all key members work in an integrated and collaborated manner using 3D design tools, 4D construction sequencing, 5D cost information and 6D project lifecycle management information. All of these tools are managed and sequenced by Industry Foundation Class (IFC) web services and standards.

However BIM Level 3 implementation is not only a step up from BIM level 2 in terms of using software tools; it is also an elevation to a new way of working. BIM level 3 will require using 3D, 4D, 5D and 6D tools within one collaborative platform; this will also require amendments and considerations in order to make the industry ready for this evolution. Questionnaire surveys and interviews with professionals and UK Government officials for a PhD research carried out by Bataw, A in 2014 have generated the following BIM level 3 Implementation concerns:

- Costs – BIM level 3 will require significant investment from those across the industry. Taking into account the costs of BIM's software and hardware as well as other costs, such as the extensive training of the different professionals, cost of technical expertise, costs of organising protocols and organising a network server to store and access the model. These costs raise the concerns of many small/ medium enterprises within the industry, failure of these enterprises in fulfilling the cost requirements will generate a large gap between them and other "BIM-Ready" enterprises in terms of work quality, winning tenders, saving time and money etc.

- Industry mind-set - The current traditional way of working will not easily adjust to the high-tech collaborative way of working that BIM can bring into the industry. BIM level 3 will completely change the way that professionals approach their day-to-day duties, from the fragmented paper method to having to work within an informational collaborative model that requires regular communication between different participants from early stages. Therefore, duties should be considered and drafted within the contractual documents to ensure that all tasks are carried out according to the collaborative nature of BIM.

- Information control - BIM level 3 relies considerably on Information Technology and software systems, this reliance raises many concerns as to the need of various control procedures in order to record and control access and inputs. Also Data protection firewall systems and data backup features can be vital to eliminate and control data corruption and data loss. The BIM model is the core data platform of the project ,one error within the model can be very costly and time wasting.

- BIM within contractual documents – BIM level 3 offers new roles and responsibilities for existing and new professions such as BIM managers and Architects and Draftsman. Therefore, all projects should include a description of these roles and outline the duties of each professional role. Also contractual documents to include Model Ownership, Liability exposure and insurance policies.

We can now understand that enterprises operating on BIM can be more advanced than those who aren't using BIM or behind with BIM levels. Yet, in the UK there is noticeable gap between the large enterprises and the small to medium enterprises; where larger enterprises seem to grasp the idea of BIM and are moving forward whilst SMEs are still mystified. This study is concerned with understanding the current position of SMEs within the BIM implementation process in the UK and their concerns on BIM.

RESEARCH METHODOLOGY

A questionnaire surveys was formed to produce a view towards the population being studied. A combination of the snowball method and the purposive method was chosen to conduct this research due to the ideas of sampling involved. It was thought that this combination was best suited because the purposive method allowed for targeting a specific population of SMEs in civil engineering who were currently involved in BIM, either by using it or by trying to adopt it. The national BIM conference, RICS 2013 in London witnessed 23 SMEs that were interested in BIM. All attended SMEs were contacted about project involvement and to undertake the survey, they were also asked to pass on the survey to other professionals and SMEs in the industry that were interested in BIM or had involvement in BIM, which generated 14 more SMEs. However, Only 20 professionals out of the invited 37 completed the SME survey, whilst the rest of SMEs did not feel they had sufficient knowledge of BIM to complete the survey.

FINDINGS AND DUSCUSSION

SMEs were asked the question, "Which definition closely matches your understanding of BIM"? The results are shown in Figure 2 below. The overwhelming choice was that Revit was the definition that best represented BIM and that it is simply 3D modelling software. This shows that many of the SMEs who are involved in BIM or interested in BIM misunderstand BIM to be just Revit and restricts in computer modelling software.

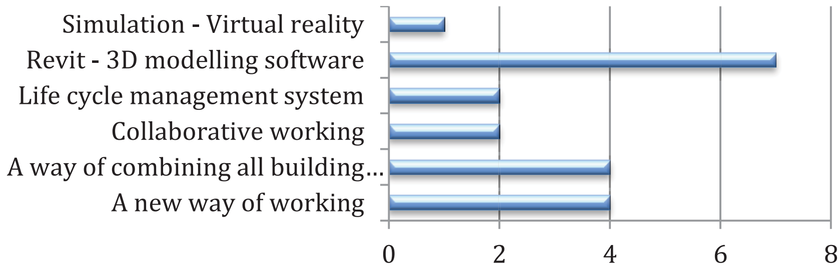

Figure 2: Which definition closely matches your understanding of BIM?

However, when participants were asked "Is your organisation currently adopting principals of BIM?" the results shown below in Figure 3. 50% of the participants (10) said yes, although when these participants were questioned on what they class as BIM adoption, 6 0ut of the 10 classed it as working with Revit. This shows that the majority are not actually using BIM and so the results for this question may have been affected by their own definition of BIM.

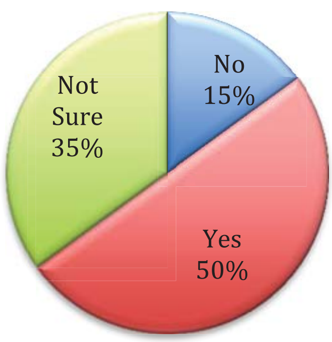

Figure 3: Is your organisation currently adopting principals of BIM

A major question was raised to the SMEs on what they thought was the biggest challenge with regards to BIM adoption. From the results shown in Figure 4, SMEs ranked the lack of government help as the biggest challenge to BIM adoption. Hence it is clear that the Government needs to do something to ease the pressure and provide some sort of a road map to guide SMEs through the implementation of BIM. The next two ranked challenges come under a similar topic that continues to remain year on year: the fact that there is a total lack of knowledge on what BIM actually is, not only for the engineers and designers but also for the clients means that the process of work will be fragmented when adopting BIM on a project.

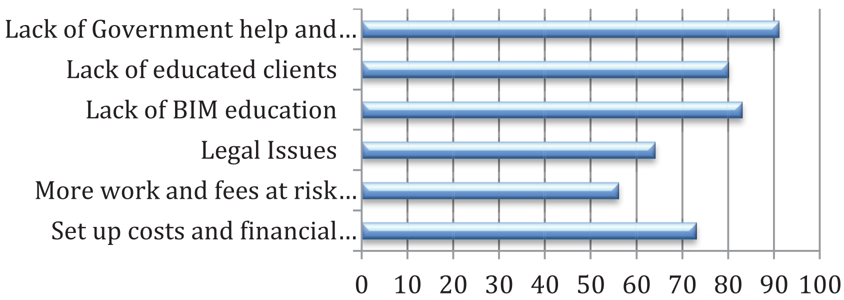

Figure 4: SME ranked challenges to BIM adoption

Only 2 of the SMEs questioned had received help from the professional institutions. Other SMEs that had not received help or advice have left comments on the lack of help and advice from professional institutions. The most appropriate comments are as following:

- The professional institutions are informed and poorly educated on BIM.
- We need support and encouragement to help push BIM forward within the SMEs
- We need lots of support from all the institutions involved
- Advice received about BIM was very misinforming and confusing
- The professional institutions do not really understand BIM fully so cannot provide useful advice.

However, almost all of the SMEs questioned have not received any help from the Government in regards to BIM implementation. The following comments were given by the SMEs on governmental advice and guidance:

- Government seems to leave it down to us to either get moving with BIM or get left behind.
- Any information they do provide seems to only relate to their own work and the much larger companies "When we asked for assistance with BIM adoption, we get no response"
- They just seem to pass the baton and no real 'how to do' information is forthcoming
- They seem to be introducing more ideas to add to BIM before we can even catch up to understand BIM at first
- I get the feeling implementation will be left down to us
- Big concerns that the people pushing BIM do not have time to slow down and help us out
- They just seem to point the way towards the recently set up BIM4SME group to have all the answers and deflect the questions
- They seem more focused too much on the major public projects, adding more inclusions to BIM before getting it right and achieving mass implementation first

All of the above comments lead to the same suggestions that the Government is leaving it up to the SMEs to implement BIM. There is a belief that the government is ploughing forward with BIM when everyone else has no idea what they are doing and again just left to get on and catch up. The only positive discovery is that the government point to a group set up by the BIM TASK group called BIM4SMEs. The group has regular meetings to solve problems and directly help SMEs with BIM so that everyone is ready before 2016. The BIM4SMEs task group meets all across the UK at the BIM regional HUBS. This is where all issues are raised and should be attended by professionals from SMEs to overtake the lack BIM knowledge and have their concerns quelled and discussed. The BIM4SME group is supposed to help SMEs resolve all their problems and get them up and running with BIM while also helping to fully understand BIM.

To understand the perception of BIM within SMEs and what the current BIM knowledge is, the question was put forward to the SMEs involved was “What do they feel is the most important benefit of BIM?” The results from this question would provide information on what SMEs expect to get or gain from implementing BIM. From the results shown in Figure 5, there is an overwhelming response that the collaborative working involved in BIM is the major benefit. Collaborative working runs right through the BIM process. Selecting a benefit relating to the actual process, rather than a product of the process, could suggest that SMEs understand the major benefits of what BIM’s collaborative way of working could bring to the industry.

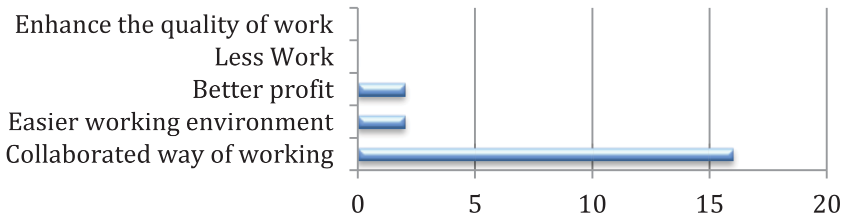

Figure 5: SMEs perceived most important benefit of BIM implementation

CONCLUSION

To conclude on the study, the SMEs and BIM survey suggests that there is still a significant lack of knowledge to what BIM actually is. This continues to follow the pattern of previous studies in 2010, 2011 and 2012 (NBS, 2012) and (NFB, 2012). Even though an increasing number of organisations are becoming more and more involved with BIM and its adoption process, in 2013 there is still evidence to suggest that SMEs do not fully understand BIM. In the conducted survey, the majority of the SMEs stated that the definition of BIM was best represented by being defined as just 3D modelling software such as Revit. However, as stated in the BIM definitions, BIM is a process and a way of working with the use of software tools rather than just software. Therefore, the results suggests that SMEs do not really understand what BIM actually is and the 50% of the participants stating that they were currently using BIM, may not actually be using the BIM process rather they are just using software.

The top ranked concerns to BIM adoption from SMEs perspective were the lack of government assistance and the lack of education, which is not only within their organisation but also with the clients they work with. It was also stated that only three of the SMEs involved in the survey had received help from professional institutions and only two SMEs received assistance from the government. However, this assistance was only in the form of financial help.

SMEs stated that they wanted more assistance from the government. There was a strong belief from the survey results suggesting that the government tends to avoid questions and enquiries asked by SMEs in regards to BIM and simply pass the baton on to another group to answer the questions. Also participants stated that concerns of the SMEs were mentioned by them at many BIM related conferences but seem to be avoided and responses were such as “everything will be fine, SMEs are at an advantage, it will all fall in place”; However, this frustrated the SMEs more and does nothing but increase the fears of BIM adoption.

There was also a strong feeling that SMEs are left on their own to sort out BIM for themselves and produce their own implementation strategy, a very bad idea considering the lack of BIM knowledge throughout SMEs and the industry in general. One of the participants commented on this option by saying “How can an organisation produce their own successful BIM implementation plan when they are severely lacking in knowledge in the topic?” There was a major feeling within the SMEs that the government continues to add extras to BIM requirements, before they have even successfully implemented basic BIM knowledge throughout the industry.

The government wants to become the number 1 nation in BIM over the next few years (Cabinet office 2011). This cannot be possible if the rest of the organisations in the UK have no idea on what is going on and what is involved. The BIM knowledge and implementation strategy needs to be implemented from the bottom up, starting with education at universities before moving on to smaller companies, medium size companies, and finally the large companies. This approach will enable the small “bugs” and problems in the process to be resolved before they get to the biggest scale and the biggest projects, thereby preventing the reputation of BIM from being damaged or misread.

Based on the conclusions, the recommendations to take forward from the findings would be to:

- Produce a set of BIM standards to attain BIM compliance within SMEs.
- Introduce accredited and certificated BIM training courses
- Provide opportunities for SMEs to work with larger BIM compliant companies to gain experience
- Suggest that the SMEs attend the BIM4SMEs group to help with BIM adoption
- Suggest that universities introduce BIM learning, with the opportunity to provide BIM learning to both students and professionals

The interest in a set of BIM standards to follow was common with all the SMEs. The SMEs indicated that a set of standards to follow would be very beneficial to them, not only for the 2016 implementation date but also for beyond that date. The SMEs believe they will be able to check their internal process with the BIM standards set process and be confident in the level of BIM compliance they have to offer.

Based on the survey questions relating to the requirement of BIM training, the responses suggest a very high interest in undertaking BIM training courses. The highest interest related to full accredited courses, either provided by the professional institutions or by universities. Having such a high interest in BIM educational courses from professionals in the industry triggers the need for universities to take part in the implementation strategy of BIM.

The study also suggested that SMEs would be interested in the idea of working with the much larger BIM compliant companies to gain experience and learn from organisations that are currently operating BIM processes. Furthermore, if rentable access is provided to SMEs for BIM software, it would quell the BIM adoption problems of the expenses involved and the financial implications with regards to implementation. The biggest offset cost of providing training, purchasing full software and managing regular updates of BIM software will be replaced by working freely alongside BIM compliant companies. This solution would resolve two of the main problems in BIM adoption: costs and training.

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STYLE OVER SUBSTANCE: THE HOMEOWNER'S DILEMMA – SPEND ON APPEARANCE, OR ENERGY REDUCTION[1]

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ABSTRACT: *This paper focusses on older domestic dwellings, specifically 1930 to 1939, which have a particular style that contribute to a recognised 'look'. The cost of retaining this style to maintain value is prioritized over any other value-add option for the home, such as energy-saving components. These properties are sought-after for that style or look, and command a certain price as a result. The British treat their home as an investment vehicle, the potential of which will be realised at some future date. As a consequence, the value of the property must be maintained above all else, in terms of appearance as much as comfort. What incentives are needed to make energy investment in the home as valued as external appearance? Can existing perceptions be changed?*

KEYWORDS: *Energy use; human comfort; period-home; maintenance, appearance;*

❖ INTRODUCTION

Housing is one of the three essential human requirements of food, clothing and shelter; while food and clothing can be obtained for very little cost – free, if necessary – shelter is extraordinarily expensive by comparison. While cause and effect can be argued, and is the subject of several other papers (Skinner, 1989; Engelhardt, 1996) a great many of the British population use their property ownership as a form of savings account, in lieu of actual cash holdings deposited with a bank (ONS, 2012). As a consequence, maintaining what a homeowner perceives as the intrinsic value of their home requires semi-constant vigilance over the appearance of the property, both external and internal. This study does not investigate properties under 'buy-to-let' ownership.

People place value in what they can see, over and above that which is invisible, or intangible (Hunter et al, 2005). Since the most common UK domestic heating system is gas boiler fired hot water distributed to radiators, with the boiler often placed behind a cupboard door (HM Government, 2010), the source of warmth is mostly silent, out of sight and usually out of mind. As such, when maintenance and/or improvements to domestic property are discussed, the subject of energy use is usually at the bottom of the list.

This paper is an offshoot of a wider study into the thermal properties and adaptability for future climate change of homes built in the inter-war period, specifically 1930-1939, a period notable for the building of the greatest number of dwellings for any decade. This was also a time when the methods of both financing and building residential properties changed considerably from what went before (Heywood, 2011a, p.39), enabling a modal shift in the aspirations and subsequent expectations of working-class people. To understand the motivations behind spending on particular aspects of a property, an overview of 1930s house types and means of construction is needed.

The 1930s house as new build

House types

The aforementioned study into the thermal properties of inter-war homes concentrates on one particular region: the development of land along the Metropolitan Railway line, by the eponymous Country Estates division (MRCE). Better known by the moniker "Metro-Land", unfettered by Green Belt legislation, which did not come into force until 1947 (Town and Country, 1947) and enabled by statute unique to any company (London Gazette, 1880), MRCE could create entire communities whose residents would use the railway to commute back to London.

Since these new developments were intended to attract Londoners of varying income levels out from "the smoke" to the fresh air and green fields of Harrow, Pinner and beyond, several types and styles of property were needed. The common denominator was the requirement to be different from the inner city, the cramped, damp, poorly-lit circumstances of many properties there, located next to industrial premises and busy thoroughfares. The majority of these homes were terraced, often back-to-back, with poor ventilation and sanitary provision (Mayhew, 1849). The sole advantage to residents was their proximity to the workplace.

[1] Citation: Hubert, J. & Bahadori-Jahromi, A. (2014). Style over substance: The homeowner's dilemma – spend on appearance, or energy reduction. In: N. Dawood and S.Alkass (Eds.), Proceedings of the 14th International Conference on Construction Applications of Virtual Reality, 16-18 November 2014, Sharjah, UAE.

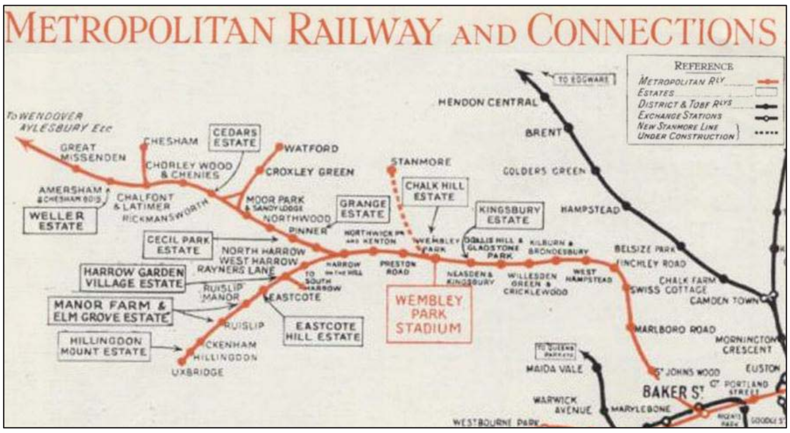

Figure 19"Metro-Land" Estates

To attract people out of London to the new estates, MRCE sold building plots to developers who would design a mix of housing types, but all with gardens front and back, indoor bathrooms, large windows and just enough variations in style to provide a sense of uniqueness to each property. The majority of these were semi-detached, interspersed with detached homes on one side of a street, or certain roads detached only. Terraced homes were almost entirely absent, save for occasional rows of four to six houses; as few echoes as possible of the London left behind were wanted.

Variations in design for each home were often cosmetic: a different leaded-glass design for the porch window; differing patterns in the tile-hung cladding above the front bay window. The object of the exercise was to entice the city-dweller out to the new 'sub-urban' districts from their convenient if otherwise poor living conditions. Prior to 1914, three-quarters of all accommodation was rented (Heywood, 2011b, p.34); the other factor in this migration of working-class people to the new suburbs in the 1930's was the expansion of mortgage lending by many of the regional Building Societies.

Paying for a new home: the Building Society

For all that much of the decade 1930-39 was a time of recession for many businesses after the financial crash of 1929, the construction industry proved to be the exception. The business of building contributed nearly one-third of British GDP (Speight, 2000) in the period 1931 to 1936. Much of this activity was enabled by access to credit for working people on a scale not seen before, albeit via some standard business practices that are illegal today. The Building Society was financier of choice for both the developer and homeowner. This was no accident: directors of building companies were often on the boards of Building Societies, and even undertook building surveys for mortgage approval. The Building Societies Act of 1939 (Building Societies Act, 1939) was inspired in part by this apparent collusion. In addition, competition amongst the Societies led to ever more ingenious ways to extend credit. A housing developer could deposit a cash sum with a Building Society – the so-called 'builder's pool' – for which security the Society could then top-up the prospective purchaser's mortgage credit, even if this exceeded their qualifying income. While parallels could be drawn with the financial excesses of the present era, there were some important differences.

The Building Societies of the 1930s were genuinely 'mutual' in that they were owned for the benefit of members rather than shareholders. There were restrictions on the type of property that could be mortgaged; freehold was fine, leasehold, buy-to-let or land development was unlikely if not forbidden under the societies' terms of business (Building Societies Act, 1894). They were as much about public service as about commerce; "what they were doing was for the general good" (Crisp, 1998a).

Construction methods

The 1930s triumvirate of land for development and extended credit was completed by a number of changes in the methods and materials used in the building of residential properties. The majority of housing in Victorian and Edwardian eras was built in bespoke form, raw materials transported to site and put together by skilled craftsmen; carpenters, bricklayers and the like. During the 1920's and into the following decade, pre-fabrication of various materials and components became possible. Mass production of items such as casement windows (Crittall Windows, 2013) and parts for staircases in a factory-controlled setting enabled a better quality of product while lowering costs at the same time. Once on site, these components could be installed by unskilled labour, i.e. people costing the builder a lot less than the craftsman of bespoke buildings. Prefabrication had its drawbacks with some materials however, such as concrete, which required accuracy in mixing and curing, and was often of poor quality because of who was doing the work. The labourers would also have been employed using new technology for the time, such as cement mixers and pneumatic drills. These items required very little training and increased the speed of house building, often to less than a week (Crisp, 1998b) from foundation to second fix.

Any regulatory oversight of the works being carried out was minimal; notwithstanding the house surveys being completed by directors of the companies building and financing the properties, local government inspectors (whose job it was to enforce building controls) were mostly overwhelmed with the number of new homes being built and the speed of construction.

The role of the jobbing labourer in the construction of houses in this period is important to the subsequent maintenance and adaptation of these homes. While the larger construction companies in Metro-Land employed tradesmen who had served some form of apprenticeship, and had a regular supply of work, many of the smaller speculative builders paid their labourers using a piece-work scheme. This was a straightforward exchange of a fixed fee for a specific task or project, dependent on the number of houses to be worked on, and the length of time required for the work. Since many of the speculative smaller building companies financed their current building project with the sale proceeds from the previous, there was some pressure to complete houses as quickly as possible. This did not help the quality of the build; furthermore, competition amongst developers to sell their homes at the lowest price resulted in their use of “cheap materials and mean dimensions and to rely on insufficiently skilled labour” (Richards, 1973).

The effect of this unskilled labour, quick build time and variable-quality materials was not immediately apparent. The houses were all sold to people looking for a different world to the London they knew, at a price they could afford. It didn’t matter that decent brickwork on the front of a property was matched equally by substandard bricks at side and rear, hidden by a coat of render or pebbledash. Likewise foundations that were often less than two feet (600mm) deep, in London clay prone to shrinkage in dry summers. These potential problems would take some time to surface, and besides were not universal: with the sheer numbers of builders and quantity of homes being built, there was still a distinct and substantive quality to the new communities.

DEFECTS IN 1930s HOMES TODAY

Common problems

Although stating the obvious, there are as many possible defects as there are parts to a home: age and neglect will affect all of them to varying degrees. The difference in older homes is that a potential replacement for any window, door, render mix or other need will be made of entirely different materials to a different size and specification that was simply unheard of or unavailable several decades ago. Hence trying to replicate an original part is often an expensive and time-consuming exercise; while there are specialist companies offering these items, each group of homes built by the many speculative builders would have used components from wherever they could source them at the best price.

There are some problems specific to 1930s homes, built as described above. The following is not an exhaustive list, but does provide an indication of what a current homeowner may need to budget for.

If the roof is still the original, it is unlikely to have any underlay or sarking felt. Provided the tiles are in good condition, that is not an issue, but the new 1930s prefabricated roof trusses were sometimes undersized, and skimped on the number of rafters (Rock, 2005, p.39), causing the roof to sag slightly. This in turn can lead to drainage problems from the roof to guttering and rain water pipes. The original homes were not very warm; the roof design was intended to be draughty, in order to keep the timbers from decay. There was little or no insulation in roof and walls – the air space in the ‘new’ cavity walls was thought sufficient (English Heritage, 2010a).

Inter-war homes relied upon coal-fired heating (gas central heating for most residential properties would not be available – or affordable – until the 1970’s), hence chimneys were essential. Rarely used now, they need ventilation if closed off, otherwise lots of problems accrue from condensation, flue masonry expanding and cracking, acid attack from condensing gases. In terms of structure, perimeter chimneys in particular had to stand proud of the highest roof point for safety reasons, but often had no support from the hipped roof! If the side wall was not tied in to the first floor joists (common when the joists ran front to back) the wall would bow out, causing the chimney to lean inwards.

The most obvious statement of intent regarding the appearance and ‘style’ of a home is the windows and front door. Many of the minor variations in the classic 1930s semi-detached home that gave each a unique 'feel' were simply in the form of coloured glass or leaded-light windows over the front door. These components are usually the flashpoint in the argument between conservation of the original style and using modern energy-saving products (Redbricks, 2011). The choice of windows frames in the thirties was between timber and metal: the quality of softwood timber was much higher then, and provided the frames were regularly maintained, as in cleaned, perhaps sanded down and painted once a year, they will still be in working condition. It is the "regular" part of that requirement that was and is so often missing. Metal frames were more often found in Art Deco designs, with curved glass windows, concrete walls and flat roofs. While these houses represent a particular style and time much more than the suburban semi, they needed a form of intensive care almost from the start, given the deficiencies in concrete production, roof design and drainage, and imperfect glass-to-metal frame connection.

Adaptations

A combination of the design limitations and material flaws in semi-detached homes in particular soon led to the new owner-occupiers making their own changes. Improving heat retention, adapting layouts and extending up and out from the original property became common practice, especially when the economy improved in the 1950's (Backhouse, 1991). Although these alterations made sense for the residents, the after-effects of some of the adaptations ended up causing more harm than good. The use of draught-proofing and over-insulation of certain areas created condensation 'hot' spots – places where humidity cannot escape. These were usually places out of sight (and therefore mind, again) behind cabinets, in roof spaces and chimney flues.

One of the first areas of the house to be extended was the kitchen. The standard design was small, usually six metres square at most, and unsuited for anything other than food preparation – eating at a table, or working with several people was out of the question. The problem is that extensions built to the rear or side were often of single-skin brick wall, with a flat roof, sometimes attached to the side garage if it existed. These conditions are ripe for condensation and damp, with poor drainage and ventilation in a space typically generating more humidity than anywhere apart from the bathroom.

DEMAND FOR 1930s HOMES

Preserving appearances?

Despite the potential drawbacks of these properties, many now more than eighty years old, the desire to own one remains undiminished (HomeCo, 2014a). Although demand generally for housing in the UK continues to outstrip supply (Wilson, 2010), the price of a "Metro-Land" semi-detached house can vary considerably within just a few square miles, viz. postcode areas HA2 and HA5 in "Metro-Land" (HomeCo, 2014b).

While the location of a house, in terms of access to amenities, transport links and appearance of immediate neighbourhood is important, a premium is attached to those properties containing original or 'as-built' features (English Heritage, 2010b). These might include a stained glass window over the front door, or the larger version in the side wall near the top of the stairs; an original fireplace, if well-maintained; a herringbone parquet floor. It is the cost of keeping specific features such as these, in addition to the regular maintenance described above, that makes spending on energy-saving options less appealing.

Figure 20Original 1930s Stained Glass Window

Value in the home

The last but possibly most important incentive for preserving the quality of an older home is the economic imperative for the homeowner. Some 19% of UK residents have no cash savings at all, while 55% have an average of just over £10,000 – less than half the average annual wage in the UK. (Scottish Widows, 2014). Very often their only investment is the house they live in. The cost of goods and services has outstripped earnings for the last five years (ONS, 2013a), regardless of age bracket. According to Redwood *et al* (2013, p.10) "14% of pensioners (1.6 million) were in households with incomes below 60% of median income, after housing costs". All the while these gloomy statistics continue, the average home in England has risen in value by a factor of 3.5 since 1996, far outstripping the rate of inflation (DCLG, 2014; ONS, 2014).
In light of these statistics, perhaps it's not surprising that the priority given to energy-saving options seems to be rather low. That was certainly the case when the properties were built, since space, warmth and 'modern conveniences' were uppermost in the original residents' minds. There were "fireplaces in the dining and sitting rooms, no longer ones that needed weekly black leading, but built of brick" and next to the bathroom the "lavatory would literally be in the 'smallest room', adjacent … but separate" (Gardiner, 2010, pp.313-317). Eight decades on, these facilities are taken for granted, and central heating has rendered the chimney more an item of decoration than any real utility. What do the current occupiers of some of these properties think of first when spending on their homes?

RESIDENT'S SURVEY
The interviews

As mentioned above, this paper is based on a continuing study looking at ways to adapt older homes to cope with future climate change. Part of this research included semi-structured interviews with a number of respondents in "Metro-Land". The sample included people living in semi-detached two-storey houses, all with solid brick walls and a first floor with three or four bedrooms. Each property had been adapted or extended in some fashion, although two had a number of original period features retained. All were privately-owned, with average length of residency over 20 years. The houses surveyed were built in the period 1929-39, and had suffered (over time) some of the problems described in section 3. The interview questions were open-ended, designed to elicit the respondents' general attitudes to energy use, rather than specific detail on, for example, dates and times a particular window might be left open. With an opportunity to talk about their views on energy saving – or otherwise - the interviewees could speak freely about whether money spent on the style and appearance of their homes would take priority over funds towards anything else, including energy reduction features.

The response

As the interviews progressed, it became increasingly clear that the questions being asked seemed inane, at best. The primary motivation for spending money on any part of a property, as stated by all the interviewees, was personal comfort. If that involved creating more light, or more space, or greater warmth, then the property was adapted as needed. The emphasis was on house as 'home' rather than investment vehicle. Questions of spending extra funds on appearance or retaining a 'style' for the house were deemed unnecessary, since those period features were just a part of the overall 'presentation' of the home if the time ever came to sell. Virtually all the properties had been modified in some way: kitchens extended, garages built over or behind, windows replaced (with uPVC frames). The installation of energy-saving features was mostly completed on an as-needed basis, such as a boiler reaching end-of-life status.

Caveats

The survey covered privately-owned homes in relatively well-off districts, (ONS, 2013b). All the homeowners were aged 50-plus, concerned about the cost of energy but not their ability to pay utility bills. Energy use was monitored on an ad-hoc basis, via online billing. There was good knowledge of the savings to be made from such options as roof and wall insulation, high-efficiency boilers and quality windows. However, there was also widespread cynicism about the use of energy in a wider context, relating possible savings at home to the high carbon usage of car and plane trips by the population at large.

RETURN ON INVESTMENT

Travelling through the "Metro-Land" region, the streets and avenues of houses display a uniform neatness and montage of well-kept frontages with few exceptions. While this belied the owners' assertions that appearance was not overly important, what is apparent in these established neighbourhoods is a default position that maintenance and appearance of older homes is one and the same. Not one of the survey respondents would consider not 'keeping up appearances' so to speak. This requires the occupier to be proactive rather than reactive, inspecting roofs, guttering, other 'points of failure' and planning for regular maintenance of their home. If period features in a 1930s home can make a difference of several thousand pounds in value, the cost of upkeep will be paid back many times over. The return on investment of additional insulation or a new boiler is seen only in respect of net energy costs, and not in terms of value to the whole house.

CONCLUSION

The homeowner's dilemma regarding funds for appearance or energy savings is not really a dilemma at all. Property values across the UK have increased beyond the rate of inflation, and likely many other financial investments over the period that each survey respondent has been resident in their home. The style or look of the house is merely an additional selling point, rather than an essential element. Only if a property is listed, or subject to specific planning rules (such as in a conservation area), will appearance necessarily come first. The majority of occupiers treat their house as a home to be lived in, and trust that their neighbours will do the same. The value of an older property depends as much on the 'quality' of the neighbourhood as any individual characteristic. While the definition of quality may vary, it would generally include the notion that virtually all properties were well-maintained, clean, but not necessarily complete with original features from the time of construction.

The perception that home appearance trumps any other factor is not the reality: personal comfort is the priority in most cases. The crux is that energy saving features installed in the house of occupant A, with their energy use habits, are difficult to value in the context of occupant B's home. Investment in domestic energy reduction will therefore need to be seen as a collective, socially responsible action to take, much as the health risks of smoking have come to be viewed. Incentives toward this should focus on the wider benefits, rather than any individual financial gain that cannot be accurately calculated.

Further research on properties in less affluent areas of the UK, with residents who have purchased their homes more recently then the respondents here (the last decade, say) may provide a different narrative.

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FIGURES

Figure 1. Metropolitan Railway (1932) *Map of London* Official Guide. Details available online: http://www.eplates.info/maps/LUmetropolitan.html. Cropped and edited image reproduced from: http://archive.lgfl.net/learningresources/curriculum/history/HistoryOfTransport/MetropolitanLine/Documents/ML%20Map%201931.jpg [Both sources accessed 6th August 2014].
Figure 2. Stained Glass leaded window in 1930s semi-detached property, Headstone Lane, Harrow. (2014) Photograph taken by the author.

AN EXPLORATORY EVALUATION OF A NEW NATIONAL ONLINE CONSENTING SYSTEM IN NEW ZEALAND[1]

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ABSTRACT: *Government passes laws both through statute and regulation to protect people. The Building Act is one of such government regulation that obligatorily requires that buildings are designed and constructed for safety, health, development and the safeguard of people from possible injury. In March 2008, Government announced a package of initiatives intended to streamline the building regulatory consenting function. One of these initiatives was to investigate the feasibility of establishing a national online building consent application and lodgement tracking system, which could be used across all local government Territorial Authorities and Building Consent Authorities in New Zealand. Government is collaborating with the private sector to develop Geobuild, a set of standards for consumers, the construction sector and government that links all aspects of the construction process from design through to procurement, construction and maintenance. Geobuild will set minimum national standards and software protocols to allow information sharing between the private and public sectors. When interoperable the Geobuild standard is expected to improve productivity, building quality and safety and reduce building cost. The study evaluates the effectiveness of this proposed national online consenting system scheme in New Zealand. The larger study programme on which this paper is based intends to gather the perception of building control practitioners on this new scheme, as a form of preliminary evaluation. Also data will be collected through a questionnaire survey to homeowners/agents of completed homes. The intent is to provide an exploratory evaluation which could help institute the new scheme in New Zealand. The paper describes this larger study to put its relevance into perspective for the New Zealand construction industry and academia. The National online consenting system will potentially accelerate and provide consistency to the building process but can only flourish if a collaboration of all affected parties provides input to their aspects of the scheme.*

KEYWORDS: *New Zealand, Online consenting, Geobuild, Consent process.*

❖ INTRODUCTION

The New Zealand building industry has come to a cross road with amendments to the Building Act, 2004. The amendment was occasioned by the shortage of building stock experienced in Auckland and Christchurch (exacerbated by the 2010 and 2011 earthquakes). The Department of Building and Housing [DBH], 2012 have reported that events will have major implication on Building Control Authorities as there is evidence that consenting services already contribute bottlenecks. Prolonging building timeframes can result in a number of unexpected costs. Delays in construction cause delays in progress payments, which can lead to late payment penalties and interest incurred on debt. Labour costs may be due to increased inspections and longer building timeframes causing poor use of subcontractor time. Delays can also expose developers to the risk of contract disputes due to late delivery. If streamlining the consenting process could address these bottlenecks it is projected that the demand versus supply shortfall would improve 2012 new dwelling consents of 16,929 (Auckland, 4,582 and Canterbury, 4,037) in addressing Auckland shortfall of 13,000 houses a year and the Governments National building shortage crisis. (Statistics New Zealand, 2012).
There is however significant and justifiable concern that an increased volume of building linked with a decrease in consenting hours would result in another mass failure (DBH, 2005) in built quality in New Zealand. For example; an increase in volume inevitably draws in less skilled labour, hence the need for experienced/competent inspectors gets greater not smaller in boom times. The repercussions of the leaky-building (Hunn, Bond & Kernohan, 2002) crisis which plagued New Zealand in the early 2000, has left a perception of discontent from society towards the construction industry and government (May, 2003). It is an evolving issue with constant reminders through lengthy judiciary suits and premature decay of buildings.

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LITERATURE REVIEW

Building Act review

The government passes laws both through statute and regulation to protect people and the Building Act purports that buildings are designed and constructed for safety, health, development and safeguard people from possible injury (Massey, 1999). At present central and local government through there building Consent Authorities are the guardians of the New Zealand building regulations, the Building Act 2004 and New Zealand Building Code 1991 (NZBC).

In August 2009 the Government announced a review of the Building Act 2004 to investigate how the Act could be updated to minimise the cost of Compliance without compromising quality of building and construction. The Government objectives (Department of Building and Housing, 2010):

- Quality homes and buildings produced through a business – enabling and efficient regulatory framework
- Consumers able to make informed decisions and have confidence in carrying out transactions in the building and housing market
- Homes and buildings produced cost-effectively by a productive sector with the right skills and knowledge
- A regulatory system that is administered in an efficient and cost effective manner.

The review found that there were weaknesses in certain parts of the system such as consumer protection, and the system was out of balance. Regulatory setting have resulted in an unduly low tolerance for risk, with a strong emphasis on central and local government protecting home owners from the risks of building defects and failures (Department of Building and Housing, 2010). The issues identified by the review were;

- Problems with ensuring responsibility sits in the right place
- Undue reliance on building consent authorities
- Fragmented administration of the building control system

The reality is that the construction sector is currently one of the least productive and least efficient contributors to the New Zealand economy. A prime example of this is the sector has had a high tolerance for rework. That is, if it doesn't get it right first time, the view was it could always sort it out later or could it be. A 2006 survey by the New Zealand Centre for Advanced Engineering found that 69% of newly-completed buildings had a defect at the time of handover to the client. Maurice Williamson the minister of Building and housing has responded "That's not good enough, and we are tackling the problem head on through the Licensed Building Practitioner scheme, the recently introduced Restricted Building Work designation, the Building Act reforms and other initiatives such as the Productivity Partnership."

The Ministry of Business, Innovation & Employment (MBIE, 2012) has reported that the construction sector accounts for about 4% of New Zealand's GDP (about the same as agriculture), but employs 8% of the country's workforce. In Australia the building and construction sector accounts for 7% of GDP, in the UK 8% and in the US 9%. Clearly there's room to improve.

The sector has become less productive over the last two decades and was one of the main contributors to a 1.2% fall in productivity across the economy between 2006 and 2009.But be assured, there is no slowing down or direction change, this is about taking what has been a poorer cousin of other parts of economic development and bringing it into the main stream. This government sees the Building and Construction sector as a vital cog in its economic growth agenda, Minister of Building and construction, Maurice Williamson (14 May, 2012).

Restricted Building Work & licensed Building Practitioners

On the 1st of March 2012 the Restricted Building Work designation took effect. Restricted Building Work is any work which is critical to the structural integrity or weather tightness of a house or small-to-medium-sized apartment building. As a rule, Restricted Building Work is work that requires a building consent. The designation is underpinned by the Licensed Building Practitioner scheme, a national building competency programme established to raise standards and accountability across the building and construction sector and to give consumers greater confidence in the quality of building work done. It underpins an efficient and accountable building sector focused on quality. The scheme has been well received by industry. By the end of April a total of 20,222 people had applied for 26,334 licences.

The introduction of Restricted Building Work also directly impacts on Building Consent Authorities (BCAs) and building officials because at the completion of restricted building work licensed building practitioners are required to provide the owner and BCA with a Memorandum or Record of Building Work to confirm the Restricted Building Work was carried out or supervised by an LBP and that identifies which LBPs were involved. While this is a relatively simple and straightforward process, it is also critical to the success of the Restricted Building Work designation, and the significance of your role can't be overstated.

From the point of view of building practitioners, the benefits of being licensed have increased considerably with the introduction of Restricted Building Work.
The combined effect of Restricted Building Work, the licensed building practitioner scheme and our Building Act reforms will be a more efficient and productive sector with less red tape, more streamlined consenting and compliance systems, and clearer accountabilities for all parties. This will be beneficial for the sector, consumers, building owners and also the economy as a whole.

The Auckland Plan: Increase house supply to meet demand

According to projections of demand in Auckland, there is a demand to build more houses per year in New Zealand than industry and systems can currently sustain (Auckland Plan 2012). Auckland's population is projected to increase to numbers between 2.2 and 2.5 million over the 3 decades (NZ Census 2013). Around 400,000 additional dwellings will be required by 2040, which means that at least 13,000 additional houses have to be built each year. The challenge is great, as of 2012 a shortfall of about 10,000 homes, and levels of house building are less than half the volume required. In the year of 2012, only 5,000 consents for new homes were issued per year in Auckland, and not all these projects have commenced. Further, in New Zealand as a whole, only about 24,000 houses are built each year, and the rebuilding of Christchurch will take up a large part of national construction capacity.
The 2012 Plan provides greater certainty for developers about when and where development will occur over the next 30 years. Auckland has a large shortfall in housing and a depressed development sector, it is a major task in achieving at least 13,000 new dwellings on average per year over the 30-year life of the plan, without urgent, bold, multi-sector action.
The Auckland Council influences housing supply through its planning, regulatory and consenting processes. For developers, the loss of equity and profit caused through delays can be more costly than the fees themselves. Time and costs across the entire development process need to be reviewed. Processes can be streamlined to increase certainty around cost and timing. The Auckland Council could move to outcomes- based consenting and other incentives for development in existing urban areas, and zone land for development in new growth areas.
Build and deliver on a multi-sector Housing Strategic Action Plan to achieve the required increase in housing supply, including options to increase affordable housing supply for first home buyers.
New Zealand's building industry is small-scale and fragmented, with a lot of silo design, construction skills shortages, and low productivity .All these factors impact on supply and house prices, combined with the post Christchurch earthquakes has provided pressure on housing nationally.

Christchurch Earthquakes

On Saturday 4th September 2010, a magnitude 7.1 earthquake occurred near Christchurch. It was widely felt over the South Island and lower areas of the North Island, and caused considerable damage in central Canterbury, especially in Christchurch. It was the largest earthquake to affect a major urban area since the 1932 Hawke's Bay earthquake. The scientific name given Darfield earthquake, though it is more widely known as the Canterbury earthquake. It produced the strongest shaking ever recorded in New Zealand. Ground near the epicentre moved up to 1.25 times the acceleration due to gravity. The earthquake was accompanied by a large surface rupture.The quake occurred at a time when majority of people were in the homes asleep and the streets were largely deserted. The lack of casualties was also due to strict building regulations and partial strengthening of older builders.
The worst damage was suffered by mainly pre-1940s buildings constructed of brick and masonry, and lacking adequate reinforcement. Some walls crumbled, with bricks cascading on to the streets. Brick chimneys toppled through tile roofs. One of the few cases of serious injury was caused by a falling chimney. A number of historic stone churches were badly damaged, although both the Anglican and Catholic cathedrals survived with minor cracking. An early Treasury estimate of the cost of the earthquake was $4 billion. Aftershocks continued for several months after the earthquake, some strong enough to cause damage to already-weakened structures. The event had left a question mark on the uncertainty of stability of older buildings and this was to come to fruition in the 2011 earthquakes with devastating consequences.
On Tuesday 22 February 2011 at 12.51 p.m. Christchurch again was struck by a magnitude 6.3 earthquake, which took the lives of 185 people and injured several thousand. The earthquake epicentre was near Littleton, just 10 kilometres south-east of Christchurch's central business district. The earthquake took place more than five months after the 4 September 2010 earthquake, but is considered to be an aftershock of the earlier quake.In contrast to the September earthquake which hit in the evening the earthquake occurred during lunch time, when many people were on the city streets. The collapse of two multi-storey office buildings – the Canterbury Television and Pyne Gould Corporation buildings accounted for 110 fatalities. Falling bricks and masonry on Manchester Street and Cashel Mall killed 11 people, and six died in two city buses crushed by crumbling walls. Rock cliffs behind houses

collapsed in the Sumner and Redcliff's area, and boulders tumbled from the Port Hills summits, with five people killed by falling rocks. Although not as powerful as the magnitude 7.1 earthquake on 4 September 2010, this earthquake occurred on a fault line that was shallow and close to the city, so the shaking was particularly destructive. The earthquake brought down many buildings previously damaged in the September 2010 earthquake, especially older brick and mortar buildings. Many historic buildings were heavily damaged, including the Provincial Council Chambers, Littleton's Timeball Station, and both the Anglican Christchurch Cathedral and the Catholic Cathedral of the Blessed Sacrament. Among the modern buildings damaged, and eventually demolished, was Christchurch's tallest building, the Hotel Grand Chancellor. Over half of the buildings in the central business district were demolished.

Liquefaction was much more extensive than in the September 2010 earthquake. Eastern sections of the city were built on a former swamp. Shaking turned water-saturated layers of sand and silt beneath the surface into sludge that squirted upwards through cracks. Properties and streets were buried in thick layers of silt, and water and sewage from damaged pipes flooded streets. House foundations cracked and warped, wrecking many homes. Despite the damage to homes, there were few serious injuries in residential houses in liquefaction areas. However, several thousand homes would need to demolished, and some sections of suburbs will probably never be re-occupied.

The government immediately activated its National Crisis Management Centre, and declared a national state of emergency the day after the quake. Christchurch's central business district remained cordoned off for more than two years after the earthquake. The weeks past the earthquake about 70,000 people were believed to have left the city due to uninhabitable homes, lack of basic services and continuing aftershocks. Neighbouring city, Timaru's population swelled by 20% and thousands of pupils registered at schools in other cities and towns. The event has put a lot of strain on central and local government in the response of replacement homes and historic / building assessment in which majority of lives were lost, (MBIE, 2013).

The Christchurch earthquakes in 2011 and 2012 had also left government agencies and civil defense workers in two minds in terms of not knowing the design or construction of buildings that were in danger of collapse in the aftermath which was highlighted in the Canterbury earthquake royal commission report 2012 recommendations;

- The Ministry of Business, Innovation and Employment should be responsible for developing and releasing public communication materials about building management after earthquakes and other disasters during and after the state of emergency.
- Information management systems should be developed as part of planning for New Zealand's building safety evaluation process.
- The Ministry of Business, Innovation and Employment should work with territorial authorities and other relevant agencies to develop a way for territorial authority building records to be electronically recorded and stored off-site.
- A clear system for identifying individual buildings should be developed and included in the plans for a building safety evaluation process.
- Land Information New Zealand should continue to work on initiatives that develop consistent national addressing protocols and make this information available to the general public

Christchurch loss of building consenting accreditation

As a consequence of the Christchurch earthquake another devastating blow was to hit in form of the local building control authority losing their accreditation. At 11.10AM on Monday, July 1st 2013 TVNZ One News reported that Christchurch City Council Building Controls Department "had today been stripped of its Building consent accreditation. International Accreditation New Zealand (IANZ) has this morning issued a decision revoking the Council's capacity as a building consents authority".

IANZ had been engaged to provide a report on the Council's consenting process as claims from property developers believed that consenting department delaying tactics were costing thousands of dollars a day. This decision was effected immediately from July 8th 2013.

The council was made aware of the intention to revoke its accreditation as a consent authority in the previous month. The Government had also threatened to intervene stating that taking into account of the enormous stress of the earthquakes, the council was still moving too slowly. Prime Minister John Key in a statement "There is a huge amount of stress on the organisation because of the rebuild, but this is slowing things down".

The New Zealand Herald also reported in an article headed "Council consents: 'critically important' that process is sped up" that the Government wanted "to develop a longer term solution that ensures the Christchurch City Council delivers timely, quality consents, and that they are again IANZ accredited" Cabinet minister Gerry Brownlee.

An average of 35 building applications were received a day in March and April through the Council according to the agenda from the month's planning committee meeting. The work load has led to council officer's reporting

"We have seen backlogs develop across all process steps-from pre-processing initial data entry through processing and into typing. The sheer volume exceeds capacity, and applicants are expressing a significant level of concern at this".

Mr Brownlee had previously hit out at the council's slow response, saying: "The council knew this workload was coming and hasn't adequately addressed it".

INTRODUCING THE INTEROPERABILITY STANDARDS

In New Zealand the laws and regulations that govern the construction of buildings and other structures are based on the Building Act 2004 (The BA04). The BA04 is administered by local government and all local governments (councils) are designated as Building Consent Authority (BCAs). BCAs have the obligation to issue building consents, undertake inspections during the construction phase, and issue Code Compliance Certificates (CCC) at the conclusion of the building process. Throughout the years councils and their BCAs have developed their own interpretations of the BA04 and have developed their own requirement's for applicants seeking building consents within their territorial jurisdiction. The results of these silo requirement has produced a bottleneck in terms of high level of inconsistency between BCAs with respect to the nature and content of information to be submitted with building consent applications.

This bottleneck creates frustration and additional costs for applicants, particular the group housing companies that have operations across New Zealand. Majority of the group housing companies offer a standard range of plans through either a branch or franchise network. Lodging a plan in various BCAs location may have varying information requirements in those stipulated in BA04.

Geobuild

The Ministry of Business, Innovation & Employment (MBIE), in collaboration with another portfolio, Land Information New Zealand (LINZ), along with the Ministry for the Environment and the private sector developing Geobuild, an integrated online strategy that will utilise smart technology that links all aspects of the construction process, from design through procurement and construction and maintenance, to achieving productivity gains and quality improvements within the built environment.

The New Zealand Government wants to see a greater level of interoperability between data sets within the construction industry to enable businesses and citizens to have improved accessibility to public information. The more information that is available the greater the decision making which enables innovation. Geobuild is the overarching concept to producing greater interoperability.

Geobuild will set minimum national standards and software protocols to allow information sharing between the private and public sectors. When interoperable, the three initial technological applications National online consenting sytems, Building information Modelling (BIM) and Location based information are expected to improve productivity, building quality and safety and lower building cost.

Access to information

Information about a particular site or building can be located in various places, such as Central and local government agencies, private businesses and even private homes as the original set were destroyed as what had happened when a local borough had burnt down along with its building consent records. Information are formatted differently and a lack of common standards limits access and use. It is envisaged that with Geobuild, land and building owners, developers, architects and designers, building and construction companies and central and local government agencies would be able to quickly access and locate information on any site. They would be able to view all aspects of the land below the ground and if the building was designed using Building information modelling (BIM) software, a 3D view of the building and its structural components. A key component of this initiative is the development of a National Online Consenting system.

Local Government

The 2013 Census, show that 1,415,550 people usually live in Auckland which is an increase of 110,592 people, or 8.5%, since the 2006 Census. It population ranks 1st in size out of the 67 districts in New Zealand. Auckland has 33.4% of New Zealand population. While Parliament is elected to deal with issues relevant to New Zealand and its people as a nation, local government enables democratic decision-making by and for local communities. Local government makes decisions about local issues and services, having regard to local needs and priorities. This

recognises that not all communities are the same, nor do they have the same issues.
In April 2009 the Government responded to the report of the Royal Commission on Auckland governance and agreed with the recommendation that there should be major changes to Auckland. At the same time the Government announced that the seven existing city and district councils and the Auckland Regional Council be disestablished and a new unitary council, the Auckland Council, be established.
As of the 1 November 2010 the Auckland Council replaced the existing Auckland Regional Council, Auckland City Council, Manukau City Council, North Shore City Council, Papakura District Council, Rodney District Council, Waitakere City Council, Franklin District Council and any associated community boards. The amalgamation of these groups signalled the beginning of a major logistic of reorganising of resources and personal. (Auckland Council, 2011)
There are 78 local authorities representing all areas of New Zealand, which consist of,11 Regional Councils, 12 City Councils (which are largely urban); 54 District Councils: and 1 Auckland Council, Which amalgamated 8 former councils on 1 November 2010). Auckland Council, as well as the city and district councils, are collectively referred to as territorial authorities (TA). There are 67 in total. Other important local government activities include Civil defence planning and emergency preparedness.
Government through housing Minister Maurice Williamson alluded to the issue of whether to consolidate, or at least better align, BCAs. In 2011 Maurice wrote to Local Government New Zealand (LGNZ) indicating that he really questioned whether retaining 69 Building Consent Authorities (BCAs) is really in the best interests of New Zealand. He also advised that he wanted to see progress on using technology to improve service delivery. The Department has met with a nationally representative group of Councils, chaired by LGNZ. The focus has been on developing a common understanding of the opportunities from system changes, particularly for building and construction sector productivity. Alignment of services nationally will produce consistency of service delivery. A national on-line consenting system will enable this. Councils will provide relevant staff to work with the Department.

National online consenting system

A major component of Geobuild, online consenting system is able to accept digital applications for building consents. All information that is submitted as part of the consent application will need to comply with the Geobuild interoperability standards. As a paperless process the electronic application will be more convenient and cheaper for users. The lodgement and application process will be the same nationally providing consistency for all BCAs. A National Online Consenting System will increase processing efficiencies, reduce costs for applicants and BCAs, and improve customer service through making the consent application process simpler and more efficient. It will also improve the customer experience by reducing application processing times, reduce processing costs and eliminating the need for applicants to visit the BCA. It would introduce a centralised, Internet based hub that receives, captures, and allows consistent processing of all building consent applications. Processing of consents, including inspections, will be conducted by Building Consent Authorities. The final aim is a service that provides for, and facilitates, the ‘end-to-end’ processing of consents using standard forms and consenting processes to provide applicants with a common experience, regardless of which Building Consent Authority (BCA) receives their consent application. Potential models from other countries have been operating, including Australia and the United Kingdom and Wales planning portal online site (Planning Portal UK, 2013). MBIE in March 2013 reported the total projected direct minimum benefits of the national online consent system are $67.3 million per annum. This took into account time saved by applicants and BCAs and benefits to contractors from the early issue of the code compliance certificate.

Application Preparation
Consent applicants access the National Online consenting system via a secure government login.
Applicants are able to revisit previously unsubmitted applications via an intuitive smart form workspace.
Digital plans which have been formatted to BIM and associated documents and specification can be uploaded to the system.

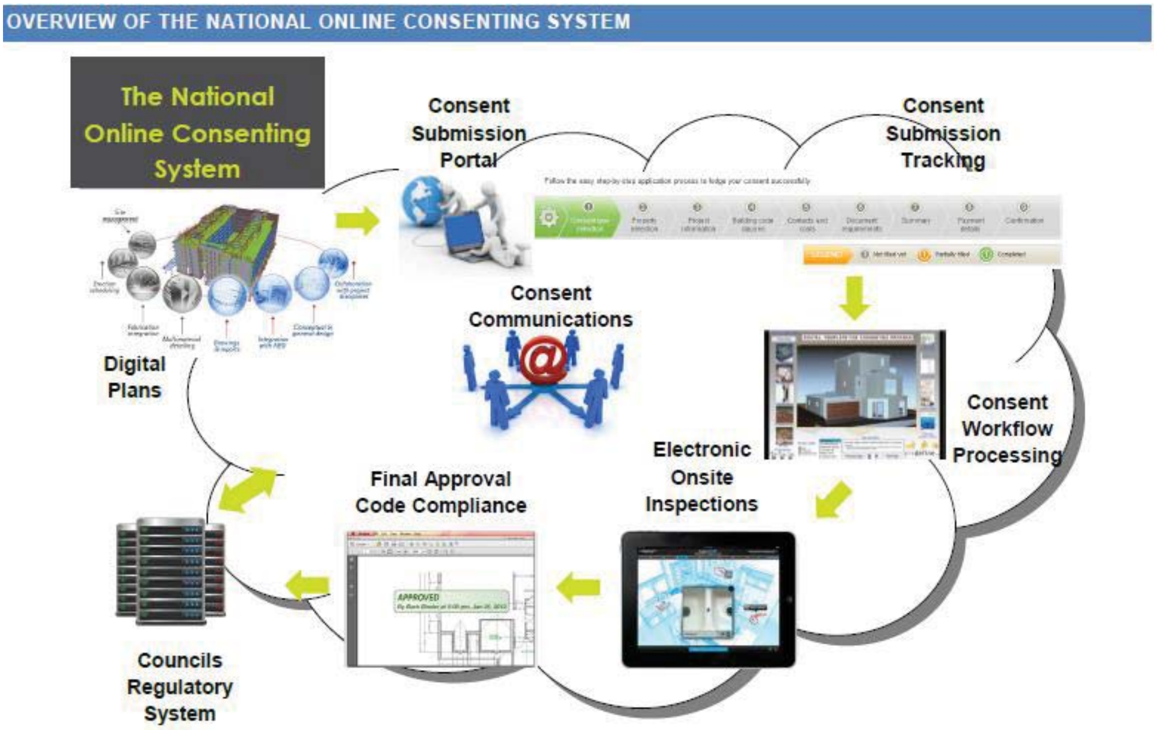
Consent submission
System verifies the completeness of the information and application fees can be paid online.

Consent processing
Consent applications are formally accepted by BCA for lodgement and processing. If any issues arise during processing further information may be requested. Once processing is satisfied and approval given, invoices are generated and notifications sent.

Inspections
Applicants request inspections for their project in which appropriate competent inspectors are allocated. Inspectors access consent information and documents through their mobile devices. Smart inspection forms and mobile devices used to submit data back to the inspection systems electronically. Inspectors also have the facility to issue electronic enforcement notices on site.

Compliance Certification
Once the final inspection has been approved by field inspector and all outstanding items addresses, the system will automatically issue the Code Compliance Certificate (CCC) and consent records update automatically. The issuing of the CCC will be the responsibility of the field inspector.

Communication
Throughout the consenting process, customers, council officers and other stakeholders are able to collaborate and communicate via a centralised communication hub within the national online.



BIM

BIM is digital software that is capable of generating a three-dimensional view of the physical, spatial and functional characteristics of a building. It allows collaboration in the design, construction and consent process to view the proposed building in a virtual environment. The data-rich program allows information critical to the integrity, design and purpose of the building to be analysed and dissected before construction begins. Contractors and designers are able to view the service area spaces in conjunction with other trades which minimises the problem of services overlapping each other's work. BIM is able to detect compromising issues in designs which will reduce crossovers and rework. BIM has extended its capability from 3D to include project management and logistic (4D), project estimating / costing (5D) and life cycle management (6D). The virtual reality of BIM provides all stakeholders are visual of what the proposed final product would look like. MBIE in March 2013 reported that an Australian review in 2010 estimated average cost savings by users of BIM to be 9.6% for architects. 6.4% for engineers, 5.5% for contractors and owners. In New Zealand, the value of non-residential building consents issued annually in 2011 was $3.64 billion. A 5.5% saving represents a potential saving of $182 million if BIM had been as a tool through the design and construction process.

Local –based information

Local and central government agencies such as LINZ gather information about the natural and built environment including what is on, under and above the land. LINZ also manages the cadastral database and land Online, the land registration system. The use of Geobuild interoperability standards in its upgrade will improve access to and usability of all location based information.

Geobuild future benefits

Information provided by Geobuild could benefit emergency response services as in the 2011 Christchurch earthquake and its aftermath. Accessing information on the construction of the building would have provided structural stability of buildings for rescue team and agency to make risked based assessment. On a global scale Geobuild may contribute with acceleration of building projects forecasted for 2020 by economist (Betts and Farrel, 2009).

THE RESEARCH

The research questions

Conclusively the study finds that the online consenting scheme could provide building regulators a tool to accelerate building processes. The fact that the scheme is online may mean that transparency is available throughout the process providing consistency without compromising cost and quality. In situations where resources are stretched and the pool of competent talent is lacking, the new scheme also provides regulatory teams a tool that can be utilized. If there is one message to take out of the leaky building crisis, it is that there is a colossal price to pay if regulators do not deal adequately with the challenges discussed in this paper, notably the shift of balance of regulatory oversight. The conclusion of the current study programme should provide a blue print for the adoption of the online consenting scheme as a regulatory tool in accelerating building processes. The fast tracking of building consenting will positively enhance the rebuilding of Christchurch for example.

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RISK ASSESSMENT AUTOMATION IN STEEL CONSTRUCTION USING IMAGE PROCESSING[1]

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ABSTRACT: *One of the computerized technologies for advanced automation is the usage of digital image processing. Digital image processing methods have been developed for progress monitoring for the past few years. Automation in safety can be reliably computed through the use of digital image processing methods. Since the steel structures construction continues to be one of the most hazard jobs in the construction industry. Therefore, an automated processor that can recognize the existence of specific site activities needs to be developed. The objective of this paper, which is part of my Ph.D. is to presents the development of a system that can detect site activities and generate the risk assessment forms for them automatically, the system can determine whether this activity exist in a given digital image by processing digital color information. For the development of the image processor, color image processing is employed, instead of grayscale image processing commonly used in previous researches.*

KEYWORDS: *IMAGE PROCESSING, CONSTRUCTION INDUSTRY, SAFETY, AUTOMATION.*

❖ ROLE OF HEALTH AND SAFETY IN CONSTRUCTION

It is a common mistake to conduct the Health and Safety exercise in order to comply with the related laws and regulations. This approach is wrong and unethical especially in the construction industry. Although this industry accounts for 5% of the general working force, it results in 22% of the fatal injuries and 10% of major injuries which are substantially bigger than its share indicating its dangerous nature.
Falling objects, moving vehicles, collapse s, and electrical shocks were the major causes of fatalities; while slips, trips, falls, and mishandling were the causes for major injuries.
The role of Health and Safety in construction sites should not be limited to the protection of workers but should be extended to cover the general public directly or indirectly in contact with these sites. An important objective of this role is the strict enforcement of the relevant laws and regulations. A significant reduction in fatalities and major injuries is being witnessed over the last years due to the improved adherence to guidelines and regulations as reported in the UK's Health and Safety Executive statistics and publications.

Health and Safety Principles

Health and safety should be regarded as one of the key targeted objectives in any business and particularly in the hazardous construction industry. However following and abiding by the various rules, regulations, and guidance associated with its implementation can prove to be a relatively complicated task for construction management teams. In order to simplify the understanding and implementation of the relevant H&S rules it might be conducive to consider the underlying principles behind them.

These principles fall under the following titles:

Health and Safety Management System:

A system should be in place which includes designations, policies, and work procedures. This system should clearly define accidents preventive measures and designate a person or persons whose job is to enforce compliance with H&S rules and deal with any possible legal obligations. The system should also set out clear steps for planning, monitoring, and controlling these measures.

Hazards Identification and Risk Assessment:
The process of risk assessment associated with the works' identified risks should be carried out in logical steps

[1] Citation: Sharqi, R. & Kaka, A. (2014). Risk assessment automation in steel construction using image processing. In: N. Dawood and S. Alkass (Eds.), Proceedings of the 14th International Conference on Construction Applications of Virtual Reality, 16-18 November 2014, Sharjah, UAE.

leading to the establishment of an approved system which helps to address these issues. These steps can be as follows;
The identification and documentation of any activity which has the potential of causing harm to the workers or the general public.
The estimation based on previous records of the probability of causing harm by the identified activity and level of severity of such harm.
The establishment and enforcement of an adequate measures response protocol to the identified risks which should be updated and maintained using the relevant bench marks set out in the applicable Health and Safety Laws and Regulations.

Working Together:

Informing and training workers, to understand and apply the above measures

The implementation of Health & Safety guidance, regulations, and recommendations related to any specific type of work is a joint responsibility. The first step in this coordinated effort is between the work force and its safety designated staff. It is the Health and Safety departments' responsibility to establish a sense of commitment to safety practices in all members of the working force. However it is not enough to restrict the Health and Safety education and coordination to the immediate work site. Customers, clients, contractors, suppliers, and other related groups should also be involved in this effort. Furthermore the implementation of Health and Safety regulations and recommendations should not be in response to accidents. It should be a proactive exercise which prevents accidents rather than respond to them.

Hazards associated with Steel Structure Construction

Design stage hazards:

Failure to incorporate safety principles during the design phase can result in unsafe site conditions and possible instability during construction while lifting, transporting, or handling of construction materials. Other considerations to be taken into account are safeguarding against progressive collapse and possible abnormal loads.

The following figure shows possible construction hazards together with their control and management

Erection stage:

During the erecting stage,the strength and stability of both temporary and permanent structures should be insured. The erection engineer must provide erection procedures and guidance on structures' stability at each stage of the construction process. A Safe Work Method Statement (SWMS) similar to the one below should also be provided.

Table (3-1)... Erector tasks

Safe Work Method Statement – Structural steel erection (sample)

What are the tasks involved?	What are the hazards and risks?	How will hazards and risks be controlled? (describe the control measures and how they will be used)
Erecting stage *(continued)*	• Unstable structure	• Builder or builder's representative and erection supervisor to inspect the frame to ensure it meets the erection engineer's specifications • Check that bolts have been tensioned to specified torques.
End of shift	• Unsecured site	• Secure all plant and equipment • Inspect site and clean up area.

Please ensure you have completed this SWMS correctly by checking the following.

☑ **I have completed the form with the following information:**
☐ I have discussed with relevant employees, contractors and HSRs – what work will be high risk, the tasks involved, and associated hazards, risks and controls.
☐ I have listed, in the first column 'What are the tasks involved?' – the main stages for the tasks involved.
☐ I have listed, in the second column 'What are the hazards and risks?' – the hazards and risks for each work task under the relevant stage of construction.
☐ I have listed, in the third column 'How will the hazards and risks be controlled?' – control measures for the hazards and risks, based on the hierarchy of control levels 1 to 4 (listed below). I have chosen a control measure (and how it is to be used) that is as close to level 1 as is reasonably practicable.
Control levels 1 to 4: **1. Eliminate risk** to health or safety associated with construction work. **2. Reduce risk** to health or safety by any one or any combination of the following: • substituting a new activity, procedure, plant, process or substance • isolating people from the hazard, such as barricading, fencing or guardrailing, or • using engineering controls, such as mechanical or electrical devices. **3. Use administrative controls,** such as changing the way the work is done. **4. Provide appropriate personal protective equipment (PPE).**
☐ The crew has been inducted to this SWMS, and briefed to stop work immediately if the SWMS is not being followed.

Fabrication stage hazards:

The task of insuring the perfect fit of members in a steel structure is the responsibility of the fabricator.

The following figure indicates the hazards and their management associated with the fabricator's work

Transportation stage hazards

The transporter should plan the routes which he intends to use beforehand and obtain the necessary authorization and permits for wide or heavy loads, restricted routes, etc.

RISK ASSESSMENT AUTOMATION

Applying automation in construction, leads to improved performance benefiting of the client, the contractor, and the environment. Adapting automation systems results in higher safety standards, better quality associated with higher accuracy, reduction of manual works, eliminations of contaminants such as dust or noise, and an increase of productivity and efficiency.

The system introducing the usage of image processing to compare real time image with reference image to detect the existence of site activities like: loading, unloading, steel erections… etc. And generate the corresponding assessment form automatically as shown in Fig.1 below

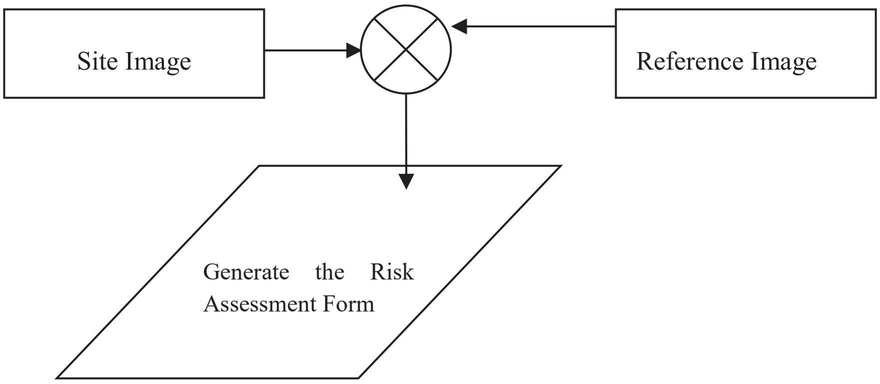

Fig.1

IMAGE PROCESSING TECHNOLOGY

Digital imaging applications in the civil engineering domain have shown significant increase, during the last decade. The development of civil engineering tools that utilize image data to assist in the design, construction and maintenance of construction projects has been enhanced by the capability to identify automatically identify site activities from the image content through direct (content- based) and indirect methodologies. The edge detection techniques, as an example, are being utilized in a variety of applications, such as detection of the type and amount of cranes in the site.

In addition, the technique is also used in image color and intensity to assess fire-damaged mortar. The notion of similarity represents a distinction between main and sudden features. For instance, main feature for something to be a crane is type of machine, generally equipped with a hoist, wire ropes or chains, and sheaves while the color is accidental. Main features are those that are shared by all individuals of a class. When comparing objects within the same class, similarity is presumably based on accidental features; similarity between objects with different classes tends to be judged by differences in their main characteristic. The ability to discriminate between features that matter and those that don't is a main learning task and needs substantial training and possibly causal theories of the domain for a review on the relationship between similarity and categorization .The problem of estimating the relative significance of many features pertains to information retrieval in general.

CONCLUSIONS

A method has been presented that finds existence of site activities in images and allows generating the Risk Assessment Forms automatically. Its performance has been demonstrated on a range of real site images. The method simultaneously considers activities over all site location, scales and orientations, and was shown to reliably detect the site activities among complex backgrounds, and handle multiple occurrences of activates in a single image.

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